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FEEDING OF SCIAENID (PISCES: SCIAENIDAE) LARVAE IN TWO COASTAL LAGOONS OF THE GULF OF MEXICO

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ABSTRACT Stomach contents analyses showed that *Leiostomus xanthurus* (8.50-12.90 mm SL) had a wide trophic spectrum (15 food categories) with copepods and eggs of invertebrates as main components. In contrast, *Micropogonias undulatus* (6.65-12.20 mm SL) ingested only six food categories (copepods, eggs of invertebrates, crustacean nauplii, barnacle nauplii, amphipods and other crustaceans). There is an overlap of 73.2 to 83.0% in the diet of these two species. *Bairdiella chrysoura* (1.17-1.92 mm SL) fed primarily on juvenile pelecypods, crustacean nauplii, eggs of invertebrates, including gasteropods and copepods. *Cynoscion nebulosus* (1.50-2.42 mm SL) ingested juvenile pelecypods, copepods, crustacean nauplii, eggs of invertebrates and tintinnids, variability in overlap (47.4 to 79.5%) between these species was affected by size of the larvae.

Introduction

Species of the family sciaenidae are abundant on sandy-muddy bottoms of shallow tropical and subtropical seas (Castro-Aguirre 1978). Most sciaenids spawn at sea and their larvae enter estuarine-lagoon systems which provide nursery habitat for postlarval and juvenile life stages (Chao and Musick 1977; Powles 1981; Shlossman and Chittenden 1981; Taniguchi 1981; Holt et al. 1981; Govoni et al. 1983; Cowan and Shaw 1988; Ditty et al. 1988; Hook 1991). *Cynoscion nebulosus*, *C. arenarius*, *C. regalis*, *Sciaenops ocellatus*, *Pogonias cromis*, *Micropogonias undulatus* and *Leiostomus xanthurus* support important commercial and recreational resources along the Atlantic coast of the United States and the northern coast of the Gulf of Mexico (Ditty 1989). Sciaenid fishes also constitute a fishery in the coastal lagoons of the southern Gulf of Mexico, with the two most important species being *Bairdiella chrysoura* and *C. nebulosus* (Reséndez-Medina 1970, 1973, 1981).

Studies of sciaenid larvae in the southern Gulf of Mexico have been conducted primarily in Laguna de Términos, Campeche and the adjacent coastal zone. Sánchez-Iturbe and Flores-Coto (1986) measured some population parameters of *B. chrysoura* larvae, and estimated the adult biomass using the annual production of eggs. Flores-Coto and Pérez-Argudín (1991) analyzed tidal effects on the passage of sciaenid larvae through Boca del Carmen in this lagoon, and Rivera-Elizalde (1988) studied the distribution and abundance of sciaenid larvae in the coastal zone of southern Gulf of Mexico.

Our study, which was conducted in Laguna de Tampamachoco, Veracruz and Laguna Madre, Tamaulipas, compared diet of sciaenid larvae and analyze dietary overlap. Little is known about the early life history of sciaenids in these two lagoons.

Study area

The Laguna Madre (Figure 1) is located in northern Tamaulipas, a Mexican state that borders Texas. The study area within this lagoon lies between the area affected by the Río San Fernando and the area between Boca de Catan and Punta Piedras. This lagoon, which is 41.5 km long and up to 14.3 km wide, has approximately nine other inlets, some of which are closed and some which are opened by dredging or by meteorological effects.

The Laguna de Tampamachoco (Figure 1) is located in northern Veracruz, a state that borders Tamaulipas. This lagoon, which is 11.0 km long and up to 1.3 km wide, is separated from the sea by the Barra Norte de Tuxpan. To the north, it has two water-links, one with Laguna de Tamiahua through a channel and another with the sea through Boca de Galindo, and to the south it is joined with the Río Tuxpan by a channel.

Materials and Methods

Zooplankton was sampled at nine stations in the Laguna de Tampamachoco during November 1987 and February, June and August 1988, and at eleven stations in the Laguna Madre during September and December 1989, and February and April 1990 (Figure 1). Samples were collected with a 505 µm mesh zooplankton net at both lagoons, additionally a 250 µm mesh net was also used in Laguna de Tampamachoco, in order to obtain a larger quantity of organisms. Both nets had a 50 cm diameter opening and were equipped with a flowmeter. Tows, which followed a circular track, were taken at the surface for a duration of 5 minutes. Samples were preserved in a 4% formaldehyde solution neutralized with sodium borate.

Measurements of larvae included standard length (SL), head length (HL), and length of both the upper and lower

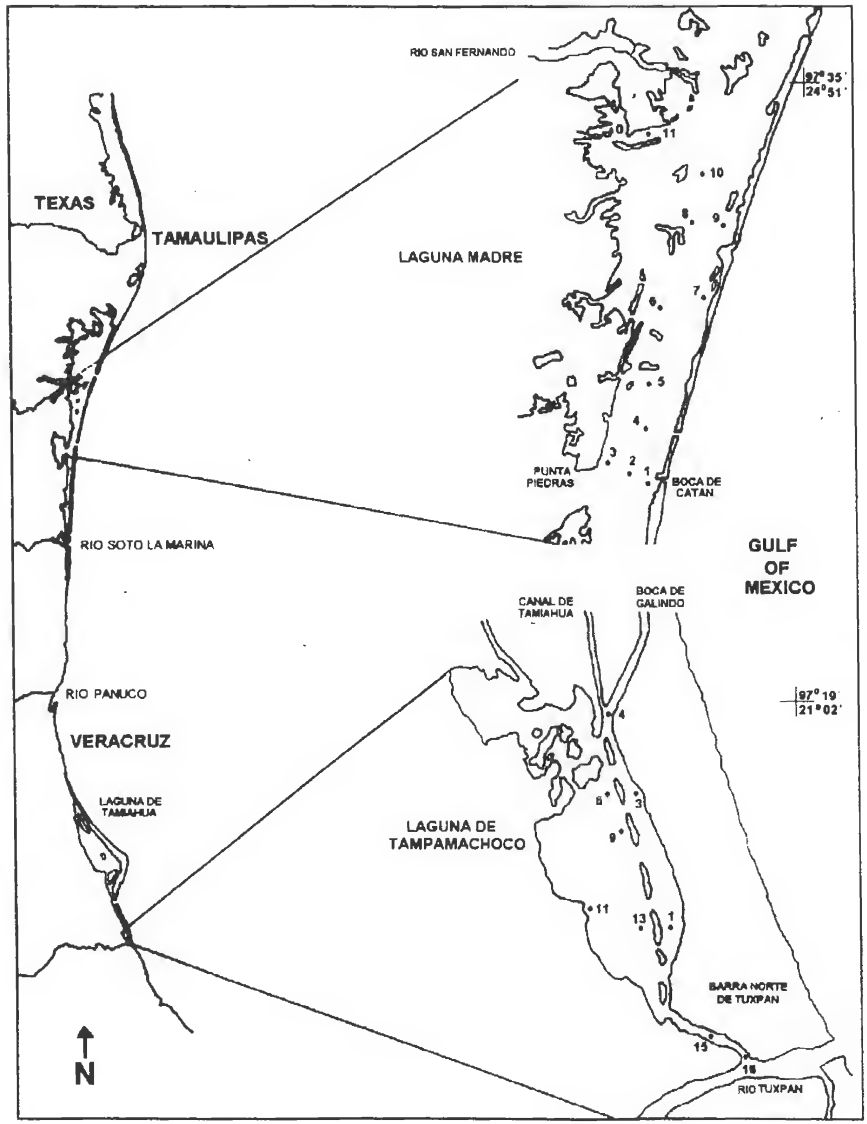

Figure 1. Study area and sampling stations. Laguna de Tampamachoco, Veracruz and Laguna Madre, Tamaulipas, Mexico.

jaws. The digestive tract was dissected and the contents were identified down to the lowest possible taxon using a wet chamber to obtain the number and type of prey ingested. Prey were measured for width. The index of relative importance (IRI) proposed by George and Hadley (1979) and modified by Towsend (1983) was calculated as follows:

$$IRI_a = \frac{100X_a}{\sum_{a=1}^{n} X_a}$$

where IRI_a = Index of relative importance for food item a, X_a = % frequency of occurrence + % total number for food item a, and n = total number of different food item found in the larvae from that sample.

The Schoener's index (1970) was used to evaluate diet overlap with values from 0 (no overlap) to 100 (total overlap):

$$a = 100\left[1\text{-}0.5 \sum_{i=1}^{n} /Px_i\text{-}Py_i/\right]$$

where a = Index of overlap, Px_i = proportion (percent by number) of food category i in the dict of species x, Py_i = proportion (percent by number) of food category i in the diet of species y, and n = the number of food categories.

The size of the mouth was measured using indices proposed by Shirota (1970) and Chao and Musick (1977) as follows:

$$D = \sqrt{2} \cdot AB$$

where D = mouth size (Shirota 1970), and AB = length of upper jaw.

$$RMS = \frac{uj \cdot lj}{h}$$

where RMS = relative mouth size (Chao and Musick 1977), uj = length of the upper jaw, lj = length of the lower jaw, and h = head length.

RESULTS AND DISCUSSION

Stomach contents of 35 *L. xanthurus* larvae from Laguna Madre were analyzed for larvae that measured from 8.50 to 12.20 mm SL. Larvae were collected between 1330 and 1410 hrs in December 1989 and at 1230 hrs in February 1990. *Leiostomus xanthurus* larvae fed on eleven different prey types. Copepods were the main diet component in December, and values of IRI ranged from 56.7 to 90.7% (Table 1). Sizes of copepods ingested ranged between 80 and 360 µm ($\bar{x}$ = 207; SD = 49) and between 60 and 320 µm ($\bar{x}$ = 148; SD = 55) in two different sample stations. The number of copepods per fish at this time of the year ranged from 14 to 27 (Table 2). This is lower than that reported by Kjelson et al. (1975) in the Newport River Estuary where larvae had 21.3 to 26.3 copepods/fish in their digestive tubes with a maximum of 36.5 copepods/fish at 1200 hrs. Kjelson et al. (1975) reported that this species had the highest food content in their digestive tracts during daylight hours, which has been observed in many marine fish larvae which are visual feeders (Hunter 1981). Copepods decreased in number in February (IRI=37.5%) (Table 1) to five copepods/fish and at the same time increased in size from 220 to 400 µm ($\bar{x}$=314; SD=50) (Table 2). The numerically dominant prey at this time of the year were non-identified eggs of invertebrates (46.2%) (Table 1).

Thirteen prey types were found in the stomach of 18 *L. xanthurus* larvae collected from Laguna de Tampamachoco in February 1988 at 1900 hrs. Larvae ranged in length from 9.10 to 12.90 mm SL and fed primarily upon copepods (IRI = 29.9%). The second most abundant prey items were appendicularians, which had an IRI of 16.7% (Table 1). The width of the ingested copepods ranged between 90 and 400 µm ($\bar{x}$ =180; SD=54) and the mean number of copepods per fish was 11 (Table 2). In general, the number of copepods ingested per fish was inversely proportional to the size of the prey. Kjelson et al. (1975) found that 99% of the food consumed by this species in the Newport River Estuary, North Carolina, were copepods, the remaining 1% was comprised of diatoms, amphipods, ostracods, barnacle larvae and crab zoea. Govoni and Chester (1990), working in the vicinity of the Mississippi River plume, found that flexion-postflexion *L. xanthurus* also eats a great diversity of prey items (11-15).

In the present study a total of 23 digestive tracts from 6.65 to 12.20 mm SL *M. undulatus* larvae were analyzed. Larvae were collected from Laguna Madre in December 1989 and February 1990 at 1410 and 1230 hrs, respectively. Similarly to *L. xanthurus*, this species fed primarily upon copepods (IRI = 44.7 to 67.0%), although the number prey types (6) was much lower for *M. undulatus* than for *L. xanthurus* (Table 3). Govoni et al. (1983) found high percentages of copepodites and copepods in larvae of both species in the northern Gulf of Mexico. These authors found that pteropods *(Limacina trochiformis)* and copepod

TABLE 1

Index of relative importance (IRI) of food items for larval *Leiostomus xanthurus* in Laguna de Tampamachoco, Veracruz and Laguna Madre, Tamaulipas, Mexico. N = number of food items, FO = frequency of occurrence, n = number of larvae examined, n′ = number of larvae with empty guts.

Diet Items	Laguna Madre, Station 8 (December-1989) Range: 9.21-12.22 mm SL (n=11, n′=0)			Laguna Madre, Station 7 (December-1989) Range: 8.50-11.40 mm SL (n=12, n′=2)			Laguna Madre, Station 2 (February-1990) Range: 9.95-12.10 mm SL (n=12, n′=0)			Laguna de Tampamachoco Station 16 (February-1988) Range: 9.10-12.90 mm SL (n=18, n′=0)		
	N	FO	IRI	N	FO	IRI	N	FO	IRI	N	FO	IRI
Copepods	293	11	56.7	166	9	90.7	55	12	37.5	200	16	29.9
Appendicularia										26	14	16.7
Barnacle nauplii	3	3	8.4				1	1	2.7	20	10	12.0
Pelecypods (Juveniles)	5	2	5.9	1	1	4.7				12	8	9.4
Pseudodiaptomus pelagicus	2	2	5.6									
Detonula sp	1	1	2.8									
Zoea							5	3	8.3	9	6	7.0
Crustacean nauplii	2	1	2.9							9	6	7.0
Crustaceans				1	1	4.7				5	5	5.7
Invertebrate eggs	15	4	12.2				189	9	46.2	16	3	4.2
Invertebrate clutch										2	2	2.3
Barnacle cypris	1	1	2.8							2	2	2.3
Amphipods	1	1	2.8				2	2	5.4	1	1	1.1
Chaetognaths										1	1	1.1
Navicula sp										1	1	1.1

TABLE 2

Size and number of copepods/fish eaten by *Leiostomus xanthurus* in two coastal lagoons of the Gulf of Mexico. S = Station, TAMPA = Laguna de Tampamachoco, Veracruz, LAMA = Laguna Madre, Tamaulipas, IRI = Index of relative importance, N = number of larvae examined, n = number of copepods; COP/FISH = copepods/fish, n′ = number of copepods measured, SD = standard deviation.

	Standard Length (mm)	N	n	COP/ FISH	IRI (COPEPODS)	Width Range (COPEPODS) (μm)	Mean Width (COPEPODS) (μm)	n′	SD	Sample Hour
TAMPA S-16 Feb-88	9.10-12.90	18	200	11.11	29.9	90-400	180	161	54	1900
LAMA S-7 Dec-89	8.50-11.40	12	166	13.83	90.6	80-360	207	160	49	1410
LAMA S-8 Dec 89	9.21-12.22	11	293	26.64	56.7	60-320	148	94	55	1330
LAMA S- 2 Feb-90	9.95-12.10	12	55	4.6	37.5	220-400	314	55	50	1230

nauplii were important in the diet of *L. xanthurus*, whereas eggs of invertebrates constituted a high percentage of the diet of *M. undulatus*.

Larvae of *B. chrysoura* and *C. nebulosus* used for feeding analyses were collected in September 1989 at 1310 hrs in Laguna Madre. Nineteen digestive tracts of *B. chrysoura* larvae between 1.17 and 1.92 mm SL contained mainly pelecypods (IRI=54.2-59.2%) and crustacean nauplii (IRI=21.7-22.9%). Larvae smaller than 1.5 mm SL also ate gastropods and eggs of invertebrates, whereas gastropods were substituted by copepods in larvae between 1.52 and 1.92 mm (Table 4). Chao and Musick (1977) found that specimens smaller than 40 mm SL fed mostly on copepods and changed to *Neomysis americana*, amphipods and other crustaceans as they grew.

Nineteen *C. nebulosus* larvae measuring 1.5 to 1.95 mm SL were found to eat mainly pelecypods (IRI=42.8%), whereas for sizes from 2.00 to 2.42 mm SL the proportion of prey changed with copepods being more abundant (IRI=34.2%) (Table 5). Reared larvae older than eight days consumed a greater dry weight of copepods than rotifers (Taniguchi 1981). This greater proportion of copepods was observed by Houde and Lovdal (1984) for larvae of this species collected in Biscayne Bay, Florida. They found that 80.9% of the food consisted of copepod nauplii, copepodites and adult copepods, with pelecypods making up a very small portion of the diet. In addition, McMichael and Peters (1989) found that copepods were the dominant prey in larvae of this species collected in Tampa Bay, Florida. Apparently larvae of this species smaller than 2.0 mm feed on prey types with low motility (pelecypods), as was also observed in laboratory cultured specimens (Taniguchi 1981).

The diet of *C. nebulosus* and *B. chrysoura* larvae did not include phytoplankton and they are consequently considered carnivorous. In contrast, the diet of *L. xanthurus* included diatoms (*Navicula* sp and *Detonula* sp), although these prey items were small and were found infrequently (Table 1). No phytoplankters were observed in the guts of *M. undulatus* in our study, whereas Govoni et al. (1983) reported the dinoflagellates (*Dinophysis* spp. and *D. caudatum*) in the youngest stages of this species.

Diet overlap was analyzed for the *M. undulatus* and *L. xanthurus* larvae collected in Laguna Madre in December. A high degree of diet overlap was found with 73.2%, which increased to 83.0% in February. Govoni et al. (1986) considers that fish larvae eat prey suitable for mechanical ingestion only; therefore food selection is restricted by prey size as well as by the perception and catching ability of the larvae. There was no significant difference between mouth size of *M. undulatus* and *L. xanthurus* (t-test, $p > 0.01$). This could be the main reason for the great diet overlap between these two species.

TABLE 3

Index of relative importance (IRI) of food items for larval *Micropogonias undulatus* Laguna Madre, Tamaulipas, Mexico. N = number of food items, FO = frequency of occurrence, n = number of larvae examined, n′ = number of larvae with empty guts.

Diet Items	Laguna Madre, Station 7 (December-1989) Range: 9.80-12.20 mm SL (n=12, n′=7)			Laguna Madre, Station 2 (February-1990) Range: 6.65-10.67 mm SL (n=11 n′=1)		
	N	FO	IRI	N	FO	IRI
Copepods	8	4	67	21	8	44.7
Barnacle nauplii				3	3	13.5
Crustacean nauplii	2	2	22.0			
Crustaceans				1	1	4.5
Invertebrate eggs				39	3	37.3
Amphipods	1	1	11.0			

TABLE 4

Index of relative importance (IRI) of food items for larval *Bairdiella chrysoura* in Laguna Madre, Tamaulipas, Mexico. N = number of food items, FO = frequency of occurrence, n = number of larvae examined, n′ = number of larvae with empty guts.

Diet Items	Laguna Madre, Station 9 (September-1989) Range: 1.17-1.47 mm SL (n=12, n′=0)			Laguna Madre, Station 9 (September-1989) Range: 1.52-1.92 mm SL (n=7, n′=0)		
	N	FO	IRI	N	FO	IRI
Copepods				4	2	12.1
Pelecypods (juveniles)	66	10	59.2	40	6	54.2
Crustacean nauplii	8	6	21.7	6	4	22.9
Gasteropods	1	1	3.5			
Invertebrate eggs	8	4	15.6	2	2	10.8

TABLE 5

Index of relative importance (IRI) of food items for larval *Cynoscion nebulosus* in Laguna Madre, Tamaulipas, Mexico. N = number of food items, FO = frequency of occurrence, n = number of larvae examined, n′ = number of larvae with empty guts.

Diet Items	Laguna Madre, Station 9 (September-1989) Range: 1.50-1.95 mm SL (n=10, n′=1)			Laguna Madre, Station 9 (September-1989) Range: 2.00-2.42 mm SL (n=9 n′=0)		
	N	FO	IRI	N	FO	IRI
Copepods	4	4	15.9	22	8	34.5
Pelecypods (juveniles)	31	7	42.8	17	5	23.2
Crustacean nauplii	16	7	33.4	11	9	32.0
Tintinnids	1	1	4.0			
Invertebrate eggs	1	1	4.0	3	3	10.3

An overlap in diet of 62.3% was recorded in September in the northern inlet of the study area (station 9) for *C. nebulosus* larvae measuring from 1.50 to 1.95 and 2.00 to 2.42 mm SL. The intraspecific diet overlap increased to 90.4% for *B. chrysoura* larvae from 1.17 to 1.47 and 1.52 to 1.92 mm SL. The percentage of overlap between *C. nebulosus* (1.50 to 1.95 mm SL) and *B. chrysoura* (1.17 to 1.47 and 1.52 to 1.92 mm SL) during September was 70.0 and 79.5%; however, the degree of overlap between larvae of *C. nebulosus* (2.00 to 2.42 mm SL) and both size ranges of *B. chrysoura* was lower (47.4 and 55.2%) (Table 6). This reduction may have been caused by an increase in length and consequently increase in mouth size of *C. nebulosus* compared to *B. chrysoura* (Table 7). It is evident that as *C. nebulosus* increased in size, copepods replaced pelecypods as the primary prey item (Table 5).

The diets of *L. xanthurus* and *M. undulatus* clearly overlapped due to two reasons: they are recruited into lagoons at the same time of the year (December-February) and they both have the same mouth size. On the other hand, although *C. nebulosus* and *B. chrysoura* coexist in space and time, they had a lower diet overlap that could be caused by a larger size mouth of *C. nebulosus* (t-test, $p < 0.01$). The different degrees of food preferences is reflected in a decrease of the diet overlap that is inversely proportional to the size.

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TABLE 6

Dietary overlap measured by Schoener's index for *Cynoscion nebulosus* and *Bairdiella chrysoura* September-1990, Laguna Madre, Tamaulipas, Mexico.

Species/size (mm SL)	*C. nebulosus* 1.50-1.95	*C. nebulosus* 2.00-2.42	*B. chrysoura* 1.17-1.47	*B. chrysoura* 1.52-1.92
C. nebulosus 1.50-1.95	100.0	62.3	70.0	79.5
C. nebulosus 2.00-2.42		100.0	47.4	55.2
B. chrysoura 1.17-1.47			100.0	90.4
B. chrysoura 1.52-1.92				100.0

TABLE 7

Relative size of the mouth of larval sciaenids in Laguna Madre, Tamaulipas, Mexico. SL = standard length, HL = head length, n = number of larvae, RMS = relative mouth size (Chao and Musick 1977), D = mouth size of fish (Shirota 1970), SD = standard deviation.

Species	SL (mm)	HL (mm)	n	RMS			D		
				Range	$\bar{x}$	SD	Range	$\bar{x}$	SD
Cynoscion nebulosus	1.50-2.52	0.42-0.90	21	0.07-0.18	0.13	0.03	0.28-0.64	0.41	0.08
Bairdiella chrysoura	1.17-1.92	0.35-0.67	19	0.05-0.16	0.09	0.04	0.20-0.45	0.29	0.09
Micropogonias undulatus	6.65-12.20	2.07-3.70	23	0.37-1.20	0.79	0.22	1.29-3.11	2.24	0.49
Leiostomus xanthurus	8.50-12.22	2.50-3.80	35	0.48-0.88	0.69	0.12	1.72-2.67	2.12	0.24

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GENETIC VARIATION IN THE CAROLINA MARSH CLAM, *POLYMESODA CAROLINIANA*

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ABSTRACT Horizontal starch gel electrophoresis was used to detect genetic variation at eight enzyme loci and five general protein loci in 11 populations of *Polymesoda caroliniana* from the Gulf of Mexico and south Atlantic coast of the U. S. Little variability was found between four of these populations along a salinity gradient in the Cape Fear Estuary, NC, and a regional trend was not observed in other populations along a latitudinal gradient. Heterogeneity analyses and dendrograms, both based on allele frequencies, suggest populations from the Gulf coast of Florida are genetically different from both a northern Gulf population (Mississippi) and Atlantic populations. The population from Mississippi was similar to populations from the Atlantic coast, all of which were similar. Heterozygosity in the 11 populations ranged between 8.11 and 28.0%, and the percentage of loci polymorphic between 37.5 and 71.4%. Populations conformed to Hardy-Weinberg expectations at greater than 95% of all loci assayed except glucose dehydrogenase, where only the populations from Fort Myers, FL, and Sapelo Island, GA, conformed to Hardy-Weinberg expectations. Electrophoretic patterns observed suggest *P. caroliniana* larvae are planktonic and effective at dispersal.

Introduction

The genetic structure of populations of marine invertebrates can be influenced by the mode of larval development (Crisp 1978, Liu et al. 1991, Hoskin 1997). Numerous investigators have demonstrated that species with planktonic larval stages show high levels of gene flow compared to species lacking such stages. For example, Hoskin (1997) investigated three gastropod species that have similar distributions in southeastern Australia: *Cominella lineolata* and *Bedeva hanleyi*, which undergo direct development in benthic egg capsules and emerge as crawling juveniles, and *Morula marginalba*, which produces planktonic larvae. *Cominella lineolata* and *B. hanleyi* exhibited high levels of variation among populations, whereas *M. marginalba* exhibited low levels of variation among populations. Janson (1987) also observed the same pattern of gene flow in brooding, i.e., egg carrying versus planktonic species of *Littorina*.

Polymesoda caroliniana, the Carolina marsh clam, is a member of the predominantly freshwater Corbiculidae and its reported range is from Virginia to Texas (Andrews and Cook 1951, Tabb and Moore 1971, Olsen 1973, Olsen 1976, Duobinis-Gray and Hackney 1982, Hackney 1983, Hackney 1985a). Cold intolerance may be the primary factor limiting its northern distribution (Hackney 1985b). It is found in a wide variety of shallow water or intertidal habitats, including salt marshes, brackish marshes, open river shores, mud banks, rock crevices and peat bogs, and is often associated with the plants *Spartina alterniflora*, *Juncus roemerianus*, *Taxodium distichum* and *Rhizophora mangle* (Andrews and Cook 1951, Tabb and Moore 1971, Olsen 1973, Olsen 1976, Duobinis-Gray and Hackney 1982, Hackney 1983, Hackney 1985a). *P. caroliniana* is considered euryhaline (Andrews and Cook 1951, Olsen 1973), occurring in habitats ranging from full strength seawater to fresh water, although it is more common and abundant in salinities less than 15‰ (Andrews and Cook 1951, Tabb and Moore 1971, Cain 1973, Hackney 1985a).

Little is known about the larval life history and dispersal mechanisms of *P. caroliniana*. Olsen (1976) spawned *P. caroliniana* in the laboratory with minimal success. He documented pelagic larval development of one individual to the straight-hinge stage, 66 h at a length of 78 µm, figures typical for other pelagic bivalve larvae. That recruitment of juvenile *P. caroliniana* does not always coincide with spawning events suggests a potential for long-term residence as meroplankton (Hackney 1983). To determine more about the larval life history and dispersal mechanisms of *P. caroliniana*, this study analyzed genetic (enzymatic) variation in 11 populations from the Gulf of Mexico and south Atlantic coast, including four along a salinity gradient in one estuary, and seven from different parts of the species' range.

Materials and Methods

Site descriptions

Samples of eleven populations were collected from estuaries along the Atlantic and Gulf coasts, from North

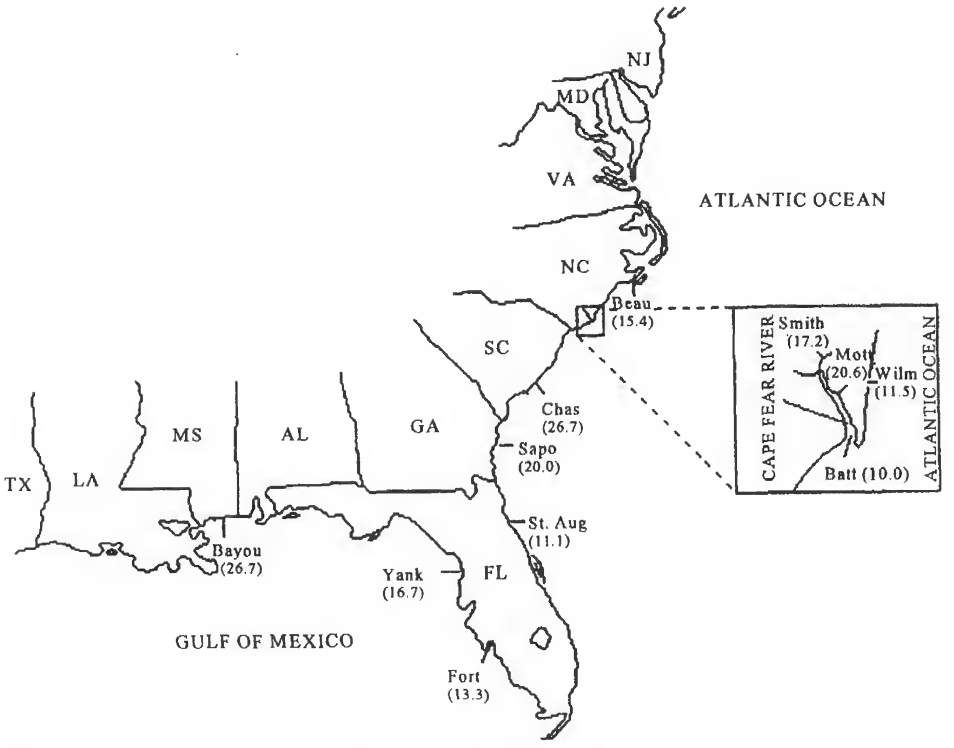

Figure 1. Location of collection sites of *Polymesoda caroliniana* along the Gulf and Atlantic coasts of the United States. Inset shows the location of four collection sites in the Cape Fear Estuary, NC. Sites are identified as follows: Beau = Beaufort, NC; Wilm = Wilmington Intracoastal Waterway, NC; Smith = Smith Creek, NC; Mott = Mott Creek, NC; Batt = Battery Island, NC; Chas = Charleston County, SC; Sapo = Sapelo Island, GA; St. Aug = St. Augustine, FL; Fort = Fort Myers, FL; Yank = Yankeetown, FL; Bayou = Ocean Springs, MS. Numbers in parentheses represent the geographic distribution of the percentage of heterozygotes at the *Gdh* locus.

Carolina to Mississippi (Figure 1). Specific site descriptions are as follows: Beaufort, NC (34.73 N): Intertidal marsh dominated by *S. alterniflora* and *J. roemerianus* along Bell Creek, a tributary of the Newport River, on the west side of County Road 1161 approximately 15 km north of Beaufort, NC, in Carteret County; Wilmington, NC (34.17 N): Intertidal marsh dominated by *S. alterniflora* and *J. roemerianus* along the Intracoastal Waterway, approximately 10 km south of Wilmington, NC, in New Hanover County. This site is along County Road 1492 approximately 4 km south of Whiskey Creek; Smith Creek, NC (34.25 N): Intertidal marsh dominated by *Spartina cynosuroides* along Smith Creek, a tributary of the Northeast Cape Fear River in New Hanover County, NC. Mott Creek, NC (34.15 N): Intertidal marsh dominated by *Scirpus olneyi* and *J. roemerianus* along Mott Creek on the west side of North Carolina Highway 1100, 14 km south of Wilmington, NC, in New Hanover County; Battery Island, NC (33.92 N): Intertidal marsh dominated by *S. alterniflora* on Battery Island, NC, in Brunswick County. The population was located approximately 100 m from the Cape Fear River on the south side of the island; Charleston, SC (32.85 N): Intertidal marsh dominated by *J. roemerianus* located where a tidal creek crosses U. S. Highway 17, 25 km north of the intersection of U. S. Highway 17 and Highway 41, north of Charleston, SC, in Charleston County; Sapelo Island, GA (31.48 N): Intertidal marsh dominated by *S. alterniflora* and *J. roemerianus* at the upper end of the Duplin River drainage basin on the west side of Sapelo Island, in Macintosh County; St. Augustine, FL (29.92 N): Subtidal population in Pellicer Creek with an average depth of 10 cm at low tide. The collecting site was under a bridge on U. S. Highway 1 that separates St. Johns and Flagler County; Fort Myers, FL (26.45 N): Intertidal mangrove island dominated by *R. mangle* located approximately 10 m southeast of a bridge where State

Highway 867 crosses Whiskey Creek, in Lee County; Yankeetown, FL (29.03 N): Intertidal, well-flooded marsh dominated by *J. roemerianus* approximately 6 km west of Yankeetown, FL, in Levy County, adjacent to a picnic area; Ocean Springs, MS (30.41 N): Intertidal marsh dominated by *J. roemerianus* located in Bellfontaine marsh south of Davis Bayou which is east of Ocean Springs, MS, in Jackson County.

Sample Processing

Horizontal starch gel electrophoresis was employed to detect genetic variation at eight enzyme loci and five general protein loci in *P. caroliniana*. At least 30 adult clams were assayed from each site with the exception of the Beaufort, NC, site (n=29; Table 1). Foot tissue was used in all assays because in *P. caroliniana* it is predominantly muscle and contains little if any visceral mass (Grater, personal observation). The whole foot was excised, weighed on a Mettler PC 2200 electronic balance (±0.05 g), ground 35 strokes in 0.5 mL of cold Tris/HCl, pH 8.0, in a Deltaware No. 96014 one mL tissue grinder, and centrifuged at 10,500 g for 20 min at 4°C in a Beckman Model J2-21 M/E centrifuge. Tracking dye (0.05 mL 0.2% bromophenol blue) was added to the supernatant fluid. Samples were then applied to two 5 mm x 5 mm Whatman 3MM chromatography paper wicks, blotted on a sheet of paper toweling to remove excess liquid and inserted into a slit cut in the gel. Each gel held 16 samples (15 data samples and a control). The control was a sample of a known migration rate from a previous gel.

Electrophoresis buffers and running and staining procedures were based on the methods of Selander et al. (1971), Harris and Hopkinson (1976) and Schaal and Anderson (1974). Based on preliminary trials, histochemical stains specific for seven enzymes — sorbital dehydrogenase (SORDH; EC No. 1.1.1.14), malate dehydrogenase (MDH; EC No. 1.1.1.37), malicenzyme (ME; EC No. 1.1.1.40), glucose dehydrogenase (GDH; EC No. 1.1.1.47), glucose-6-phosphate dehydrogenase (GD; EC No.1.1.1.49), glutamate-oxaloacetate transaminase (GOT; EC No. 2.6.1.1) and esterase (EST; EC No. 3.1.1.1) — and one general protein stain (Ptn) were employed in this study.

Statistical Analyses

Multiple loci encoding the same enzyme were designated by consecutive numbers, with "1" denoting the slowest migrating enzyme. Alleles within each locus were scored by designating the most common allele as 100. Other alleles were numbered according to their relative anodal distance from the most common allele. *Got* electromorphs resolved into distinct zones but not always into distinct genotypes and thus were lumped into the following classes: 1) homozygotes of the most common allele, 2) heterozygotes with the most common allele, and 3) all other genotypes. The five proteins visualized with general protein stain were presumably nonenzymatic muscle contractile proteins and were distinguished as individual loci based on the irregularity of the spacing between electromorphs, the homogeneity of staining intensity of electromorphs, and the reproducibility of these results.

The percentage of individual allele types at each locus was calculated following Hartl (1988). A locus was considered monomorphic if the frequency of the least common allele was less than 1% (Hartl 1988). The average percentage of loci that were heterozygous in an individual was determined for each population following Hartl (1988).

Independence of allele associations was tested with two-way and multiway contingency table analyses using the G-statistic (Sokal and Rohlf 1995). All possible pairwise combinations of loci within each population were examined. The G-test, analogous to the Chi-square test (Sokal and Rohlf 1995), should not be used when classes contain fewer than five observations (Hartl 1988). When numbers in an allele class were less than five, classes were combined as follows. In diallelic enzyme systems, heterozygotes were lumped with the smaller homozygous class. In multiple allele systems, the following three classes were created: 1) homozygotes of the most common allele, 2) heterozygotes with the most common allele, and 3) all other genotypes.

Two tests were used to determine whether proportions of genotypes conformed to Hardy-Weinberg expectations. Haldane's (1954) exact test for randomness of mating was used for diallelic systems and for multiple allele systems for populations in which only two alleles were observed. Where multiple allele systems were found, the Chi-square test of Hardy-Weinberg expectations was used (Hartl 1988). However, in multiple allele systems, numbers in expected classes were frequently less than five and combining of classes was necessary.

A G-test was employed to test heterogeneity of allele distributions for each locus in all populations (Sokal and Rohlf 1995). Where heterogeneity was observed, the source of the heterogeneity was determined by calculating a G-statistic for each population. G-tests and Hardy-Weinberg analyses were corrected for α-errors associated with repeated testing using the Bonferroni correction (Sokal and Rohlf 1995).

Three levels of population structure were estimated with *F*-statistics: individual within subpopulation (F_{IS},

TABLE 1

Number of animals scored at each locus. Sites are identified as in the legend of Figure 1.

Locus and Electromorph	Populations										
	Beau, NC	Wilm, NC	Smith, NC	Mott, NC	Batt, NC	Chas, SC	Sapo, GA	St. Aug, FL	Fort, FL	Yank, FL	Bayou, MS
Sordh	8	--[a]	30	37	--	--	--	--	--	30	24
Mdh	29	30	30	91	52	30	38	51	45	30	30
Me	24	30	30	66	52	30	35	29	45	30	30
Gdh	26	30	29	34	52	30	15	36	45	30	30
Gd	17	28	30	36	41	29	--	35	37	30	29
Got	21	--	--	--	52	30	38	36	26	22	--
Est-1	28	28	28	38	17	30	14	35	30	29	29
Est-2	24	29	--	36	7	28	9	31	28	28	26
Ptn-1	--	--	30	30	--	30	15	--	15	30	15
Ptn-2	--	--	30	30	--	30	15	--	15	30	15
Ptn-3	29	--	--	37	37	30	19	36	45	15	15
Ptn-4	29	--	--	37	37	30	19	36	45	15	15
Ptn-5	--	15	--	10	7	30	--	20	13	15	30

[a]Dashed line indicates no data collected

positive values indicate heterozygote deficiencies), subpopulation within region (F_{IT}), and region within total area sampled (F_{ST}). *F*-statistics were conducted using Genetic Data Analysis software (Lewis and Zoykin 1997).

Genetic differentiation between populations was estimated with Nei's unbiased estimates of genetic identity and genetic distance (Nei 1987). Nei's genetic identity estimates the proportion of alleles identical in two populations, and Nei's genetic distance estimates the mean number of net codon substitutions between two populations, assuming that individual mutation rates are similar and individual substitution events are independent (Nei 1987). These estimates were conducted using Gendis software (Department of Genetics, University of Georgia; Masatoshi Nei, Institute of Molecular and Evolutionary Genetics, University of Pennsylvania).

A matrix of Nei's genetic distance values was used to construct a tree of relatedness. The method employed was the average distance method or unweighted-pair group method with arithmetic mean (UPGMA), which assumes that the rate of gene substitution is constant (Nei 1987). The BMDP software used was supplied by the University of Georgia.

RESULTS AND DISCUSSION

At several loci, allele frequencies were dissimilar between the two populations from the Gulf coast of Florida (Fort Myers and Yankeetown) and all other populations (Table 2). For both Fort Myers and Yankeetown populations, at the *Gdh* locus, the frequency of the 100 allele was highest and the frequencies of the 106 and 113 alleles lowest. At the *Me* locus, Fort Myers and Yankeetown alleles were fixed for the same allele; however, the Smith Creek, NC, population was also fixed for this allele. For the 100 allele at the *Gd*, *Got*, and *Est-2* loci, frequencies at Fort Myers were highest.

Davis Bayou, MS, allele frequencies were more similar to those populations from the East coast than to those of other populations from the Gulf coast at all loci except *Mdh*. Alleles unique to the Gulf coast were observed at this locus (Table 2). Allele frequencies did not consistently increase or decrease at four sites along the salinity gradient in the Cape Fear Estuary, or along the latitudinal gradient.

There were sufficient data in allele classes to conduct 13 tests of 65 possible for independence of allele association. No tests were significant at $p<0.05$, indicating lack of linkage or other co-selection for these locus pairs.

Adjusted estimates of percent heterozygosity and percent of polymorphic loci are similar to those of the bivalves *Rangia cuneata* and *R. flexuosa* (Foltz et al. 1995). Heterozygosity ranged between 8.1% at Fort Myers and 28% at Wilmington, NC (Table 3), where data were not obtained for four of the five nonenzymatic loci. Since non-enzymatic loci were monomorphic (Table 2), this heterozygosity estimate would probably be lower if monomorphic data were obtained. The other nine heterozygosity values were all between 14.0 and 21.6 % (Table 3).

The percentage of polymorphic loci ranged between 37.5% at Smith Creek and 71.4% at Wilmington. The other nine estimates were between 50.0 and 60.0% (Table 3). Estimates were generally higher at sites in which data were not obtained for several nonenzymatic loci (Table 2; Table 3). The estimate for Smith Creek could be too low, for gels were unscorable at two loci polymorphic at other sites, and allele frequencies were fixed at three other enzymatic loci, more than at any other site (Table 2).

Populations of *P. caroliniana* were in Hardy-Weinberg equilibrium at greater than 95% of all loci scored other than *Gdh*. Only the populations from Fort Myers and Sapelo Island met Hardy-Weinberg expectations at this locus (Table 3). When combining allele classes to test for Hardy-Weinberg equilibrium at the *Gdh* locus, it would have been possible to obtain significance and nonsignificance of the Chi-square depending on how classes were combined. However, overall low numbers of heterozygotes at the *Gdh* locus indicate these populations actually do not meet Hardy-Weinberg expectations (Figure 1; Table 4), which suggests selection is operating against them, for if inbreeding were occurring, other loci would have failed to conform to Hardy-Weinberg expectations.

For the Fort Myers population, the frequency of the 100 allele was so high (0.91) that expected numbers of heterozygotes containing alleles other than 100 were low, often near zero. This is consistent with the low observed numbers of heterozygotes, and the resulting Chi-square value was not significant (Table 3). The Sapelo Island population conformed to Hardy-Weinberg expectations only after the Bonferroni correction was employed.

In this study, populations of *P. caroliniana* were sampled along a salinity gradient in the Cape Fear Estuary, NC, and along latitudinal gradient from North Carolina to Mississippi, but allele frequencies showed no clinal pattern with either salinity or latitude (Table 2). This, coupled with results of Hardy-Weinberg analysis, suggests there is gene flow among populations within and between estuaries along the Atlantic coast, i.e., *P. caroliniana* are effective at dispersal (Table 3). Also, electrophoretic patterns observed in this study are similar to those of other marine invertebrates with planktonic larvae, i.e., low levels of variation exist among populations (Crisp 1978, Liu et al. 1991, Hoskin 1997). *F*-statistics do indicate there is some population

TABLE 2

Allele frequencies observed in 11 populations of *Polymesoda caroliniana*. Sites are identified as in the legend of Figure 1.

Locus		Beau, NC	Wilm, NC	Smith, NC	Mott, NC	Batt, NC
Sordh	106		-----[a]		0.030	-----
	100	1.0	-----	1.0	0.97	-----
Mdh	105					
	100	1.0	1.0	1.0	1.0	1.0
	94					
	89					
Me	100	0.69	0.92	1.0	0.91	0.79
	82	0.31	0.080		0.090	0.21
Gdh	119	0.080	0.050		0.060	0.10
	113	0.23	0.33	0.39	0.16	0.29
	106	0.42	0.22	0.14	0.26	0.21
	100	0.23	0.40	0.45	0.52	0.38
	89	0.040		0.020		0.020
	82					
Gd	100	0.53	0.29	0.68	0.60	0.70
	87	0.47	0.71	0.32	0.40	0.30
Got	100	0.64	-----	-----	-----	0.78
	Variant	0.36	-----	-----	-----	0.22
Est-1	100	0.45	0.48	0.61	0.54	0.65
	95	0.55	0.52	0.39	0.46	0.35
Est-2	100	0.58	0.47	-----	0.46	0.64
	96	0.42	0.53	-----	0.54	0.36
Ptn-1		-----	-----	1.0	1.0	----
Ptn-2		-----	-----	1.0	1.0	1.0
Ptn-3		1.0	-----	-----	1.0	1.0
Ptn-4		1.0	-----	-----	1.0	1.0
Ptn-5		-----	1.0	-----	1.0	----

[a]Dashed line indicates no data collected

TABLE 2 (Continued)

Locus		Chas, SC	Sapo, GA	St. Aug, FL	Fort, FL	Yank, FL	Bayou, MS
Sordh	106	-----	-----	-----	-----	0.030	
	100	-----	-----	-----	-----	0.97	1.0
Mdh	105					0.030	
	100	1.0	1.0	1.0	0.99	0.92	0.98
	94					0.030	
	89				0.010	0.020	0.020
Me	100	0.87	0.93	0.91	1.0	1.0	0.98
	82	0.13	0.070	0.090			0.020
Gdh	119	0.070	0.10	0.070		0.030	0.030
	113	0.30	0.20	0.31	0.050	0.070	0.17
	106	0.22	0.23	0.22	0.010	0.13	0.25
	100	0.30	0.47	0.35	0.91	0.75	0.43
	89	0.080		0.050	0.030	0.020	0.050
	82	0.030					0.070
Gd	100	0.50	-----	0.66	0.80	0.40	0.64
	87	0.50	-----	0.34	0.20	0.60	0.36
Got	100	0.65	0.70	0.56	0.88	0.77	-----
	Variant	0.35	0.30	0.44	0.12	0.23	-----
Est-1	100	0.42	0.71	0.51	0.73	0.62	0.55
	95	0.58	0.29	0.49	0.27	0.38	0.45
Est-2	100	0.45	0.67	0.44	0.89	0.70	0.64
	96	0.55	0.33	0.56	0.11	0.30	0.36
Ptn-1		1.0	1.0	-----	1.0	1.0	1.0
Ptn-2		1.0	1.0	-----	1.0	1.0	1.0
Ptn-3		1.0	1.0	1.0	1.0	1.0	1.0
Ptn-4		1.0	1.0	1.0	1.0	1.0	1.0
Ptn-5		1.0	-----	1.0	1.0	1.0	1.0

TABLE 3

Chi-square values for Hardy-Weinberg analysis, percent heterozygosity and percent loci polymorphic for 11 populations of *Polymesoda caroliniana*. Sites are identified as in the legend of Figure 1.

Site	Chi-square values for Hardy-Weinberg Equilibrium								Heterozygosity	Loci Polymorphic
	Locus									
	Sordh	*Mdh*	*Me*	*Gdh*	*Gd*	*Got*	*Est-1*	*Est-2*	(%)	(%)
Beau, NC	0.00	0.00	4.47	23.5*	5.14	4.88	3.72	0.522	21.6	60.0
Wilm, NC	-----[a]	0.00	0.192	33.5*	4.07	-----	0.215	2.55	28.0	71.4
Smith, NC	0.00	0.00	0.00	15.4*	2.55	-----	0.0250	-----	15.5	37.5
Mott, NC	0.00196	0.00	0.596	14.9*	0.245	-----	6.96	1.09	14.0	50.0
Batt, NC	-----	0.00	3.51	19.7*	0.0475	1.56	4.43	0.137	19.0	60.0
Chas, SC	-----	0.00	0.602	33.0*	0.417	7.55	2.04	5.03	18.8	50.0
Sapo, GA	-----	0.00	0.172	8.14	-----	0.231	0.761	0.300	14.8	50.0
St. Aug, FL	-----	0.00	0.200	38.8*	2.23	1.82	0.558	0.816	18.3	60.0
Fort, FL	-----	0.00	0.00	0.665	6.91	2.04	3.38	0.342	8.11	50.0
Yank, FL	0.0170	21.2*	0.00	16.4*	0.998	1.36	0.00170	0.221	14.4	53.8
Bayou, MS	0.00	0.0170	0.00	16.8*	0.0640	-----	1.24	1.29	16.6	50.0

*$p<0.05$

[a]Dashed line indicates no data collected

TABLE 4

***F*-statistics of 11 populations of *Polymesoda caroliniana*. The estimates of three levels of population structure are as follows: F_{IS} = individual within subpopulation, F_{IT} = subpopulation within region, and F_{ST} = region within total area sampled.**

Locus	F_{IS}	F_{IT}	F_{ST}
Sordh	-0.150	0.905	0.907
Mdh	0.428	0.443	0.259
Me	-0.135	-0.033	0.090
Gdh	0.731	0.752	0.077
Gd	0.050	0.118	0.072
Est-1	0.153	0.158	0.006
Est-2	-0.050	0.025	0.071
Overall	0.235	0.323	0.115

subdivision within regions, but differentiation over the entire study area is moderate (Table 4). Our results confirm Olsen's (1976) observation that *P. caroliniana* larvae are planktonic and lend support to Hackney's (1983) hypothesis that *P.caroliniana* larvae are capable of long-term residence as meroplankton.

Electrophoretic patterns between *P. caroliniana* populations from the Atlantic and Gulf coasts are unique when compared with those of many other studies. Numerous investigators have described distinct genetic differences between Atlantic and Gulf populations of many species using various genetic markers (Reeb and Avise 1990, Avise 1992, Karl and Avise 1992, Sarver and Foltz 1992, Felder and Staton 1994, Foltz et al. 1995). In this study, heterogeneity analyses and dendrograms, based on allele frequencies, indicate that populations assayed from the west coast of Florida (Fort Myers and Yankeetown) are genetically distinct and physically isolated from other populations assayed, and that a population from Mississippi is genetically more similar to Atlantic coast populations than to west coast Florida populations (Table 5a and b; Figure 2a and b).

Heterogeneity analyses revealed significant heterogeneity in population allele frequencies at each of five loci: *Me*, *Gdh*, *Gd*, *Got* and *Est-2* (Table 5a). Much of this heterogeneity was due to populations from the west coast of Florida, with clams from Fort Myers significantly heterogeneous at all five loci and clams from Yankeetown at three (Table 5b). Two loci were heterogeneous in clams from Beaufort and Smith Creek, while clams from Wilmington, Battery Island and Davis Bayou were heterogeneous at one locus (Table 5b).

In this study, data were obtained for all 11 populations at only four enzymatic loci (Table 2); therefore, a dendrogram was produced with data from only these four loci (Figure 2a). In this dendrogram, the maximum genetic distance (D) separating populations other than Beaufort, Fort Myers and Yankeetown was 0.02. Beaufort was separated from this group by D=0.05. Fort Myers and Yankeetown were separated from each other by D=0.01, and from all other populations by D=0.06. These three populations represent the northern and southern extremes of the study area.

Another dendrogram was produced, using six loci (Figure 2b), by excluding two populations in which there were missing data, Smith Creek and Sapelo Island (Table 2). In this dendrogram, the maximum D separating populations other than Fort Myers and Yankeetown was 0.04. Fort Myers and Yankeetown were separated from each other by D=0.05, and these two populations were separated from all others by D=0.08.

Numerous models have been employed to explain genetic differences and similarities between Gulf and Atlantic populations (Bert 1986, Reeb and Avise 1990, Avise 1992, Karl and Avise 1992, Felder and Staton 1994) and each could be invoked in some form here. Most notably, in an analysis of restriction fragment length polymorphisms in single-copy nuclear DNA of the American oyster, *Crassostrea virginica*, Karl and Avise (1992) found pronounced discontinuities between Gulf and Atlantic populations. These findings were similar to those of a mitochondrial DNA (mtDNA) survey of *C. virginica* (Reeb and Avise 1990), but were contradictory to those of an allozyme survey of *C. virginica* in which little or no population subdivision between Gulf and Atlantic populations was observed (Buroker 1983). Also, mtDNA surveys of other coastal taxa, including horseshoe crabs, toadfish, black sea bass, diamondback terrapins, and seaside sparrows (Avise 1992) reveal pronounced discontinuities between Gulf and Atlantic populations. Karl and Avise (1992), Avise (1992), and Reeb and Avise (1990) suggest this subdivision occurs as a result of vicariant historical processes, and Karl and Avise (1992) suggest the homogeniety of allozyme polymorphisms observed in *C. virginica* may be the result of balancing selection, which can counter the influence of genetic drift.

In the current study, only three Gulf coast sites were sampled and dendrograms are based on data from only four to six loci; therefore, genetic relationships observed in the dendograms must be considered preliminary (Nei 1987). One possible explanation may be that the existence of the Suwanee Strait or Gulf Trough, which isolated peninsular Florida from the continental US, may have facilitated gene

TABLE 5a

Heterogencity G-test values for 11 populations of *Polymesoda caroliniana* pooled.

	Locus							
	Sordh	*Mdh*	*Me*	*Gdh*	*Gd*	*Got*	*Est-1*	*Est-2*
df	4	30	10	50	9	6	10	9
$G_{Heterogeneity}$	5.34	31.10	79.87*	203.4*	54.77*	22.23*	17.55	35.68*
G_{Pooled}	0.001800	0.4044	-0.04260	0.02240	-0.01000	-0.02000	-0.04600	-0.02000
G_{Total}	5.342	31.50	79.83*	207.6*	54.76*	22.21*	17.51	35.66*

*p<0.05

TABLE 5b

Heterogeneity G-test values for individual populations of *Polymesoda caroliniana*. Sites are identified as in the legend of Figure 1.

Site	Locus				
	Me	*Gdh*	*Gd*	*Got*	*Est-2*
Beau, NC	18.57*	19.97*	0.5592	0.9136	0.002000
Wilm, NC	0.03900	8.367	21.61*	-----[a]	3.489
Smith, NC	11.45*	15.02*	2.090	-----	-----
Mott, NC	00.007200	7.903	0.004200	-----	4.853
Batt, NC	13.77*	9.506	3.674	2.442	0.1790
Chas, SC	1.149	13.12*	2.036	1.048	-8.137
Sapo, GA	0.3430	3.583	-----	0.06360	0.4776
St. Aug, FL	0.01140	8.174	1.218	7.819	5.785
Fort, FL	17.17*	85.10*	14.03*	9.071*	25.69*
Yank, FL	11.45*	19.94*	9.034*	0.8512	2.844
Bayou, MS	5.879	12.86*	0.4918	-----	0.4814
G_{Total}	79.83*	203.5*	54.75*	22.21*	35.66*

*p<0.05

[a]Dashed line indicates no data collected

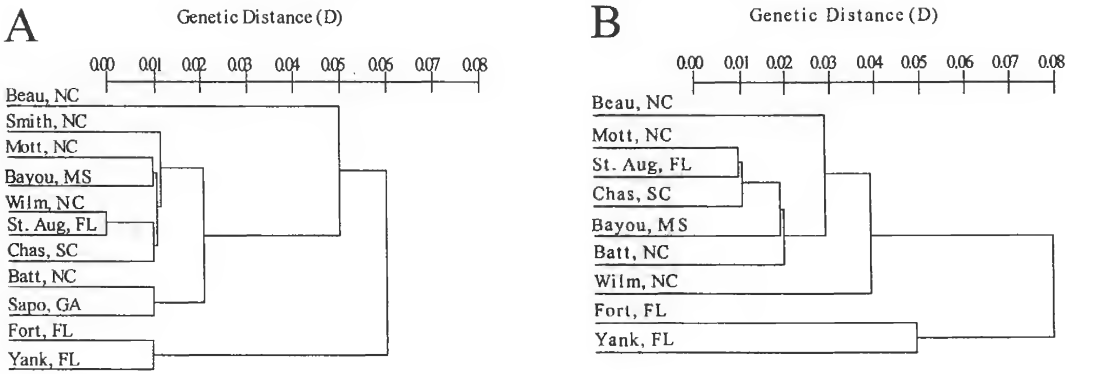

Figure 2. (A) UPGMA dendrogram based on electromorph frequencies at four loci (*Mdh*, *Me*, *Gdh*, and *Est-1*) in each of 11 populations of *Polymesoda caroliniana*. (B) UPGMA dendrogram based on electromorph frequencies at six loci (*Mdh*, *Me*, *Gdh*, *Gd*, *Est-1*, and *Est-2*) in each of nine populations of *Polymesoda caroliniana*. Sites are identified as in the legend of Figure 1.

flow between the Mississippi population and Atlantic coast populations, while isolating west coast Florida populations. The existence of the Suwanee Strait is controversial, and Webb (1990) notes that biological arguments for the existence of the Suwanee Strait ". . . based on various degrees of endism in the biota of the central peninsula, would be just as well satisfied by the existence of habitat islands as by the existence of a hypothetical seaway to produce real islands."

A second explanation may be with the onset of glaciation, populations of *P. caroliniana* from the isolated southern portion of the range may have retreated south to the Yucatan or the larger Caribbean island subtropical habitat where some genetic divergence may have occurred. With glacial retreat and the gradual northern movement of ecosystems these populations may have returned to Florida along with subtropical habitat. The presence of alleles unique to Gulf coast populations suggests there once was, and/or currently is, gene flow between them.

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Effects of the Burrowing Brittlestar, *Microphiopholis gracillima* (Echinodermata: Ophiuroidea), on the Flux of Lithium, an Inert Tracer, Across the Sediment-Water Interface

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EFFECTS OF THE BURROWING BRITTLESTAR, *MICROPHIOPHOLIS GRACILLIMA* (ECHINODERMATA: OPHIUROIDEA), ON THE FLUX OF LITHIUM, AN INERT TRACER, ACROSS THE SEDIMENT-WATER INTERFACE

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ABSTRACT Burrowing and ventilation activities of infaunal organisms have been shown to affect geochemical processes in sediments and at the sediment-water interface. Although burrowing brittlestars are dominant in many benthic environments, their role in these processes is poorly known. We tested the effect of the amphiurid brittlestar, *Microphiopholis gracillima*, on the flux of lithium ion from the sediment to the overlying water by using sediment cores with false bottoms for continuous flow of a Li^{+1}-seawater solution. Brittlestars at densities of 300 and 600 individuals m^{-2} caused a twofold increase in the rate that Li was transported through the sediment. Density of brittlestars appeared to have no effect on the flux of Li^{+1} from the sediment, indicating a possible threshold beyond which density increases do not influence fluxes of solute from the sediment.

Introduction

The effect of infaunal organisms on sediment characteristics has been well documented (Rhoads 1974, Rhoads and Boyer 1982, Aller 1982). Through their burrowing, feeding and ventilation activities, infauna can modify physical properties of the sediment such as shear strength, sorting of grain size, and porosity (Rhoads 1974, Rhoads and Boyer 1982, Aller and Aller 1992). They can also influence the flux or exchange of dissolved chemicals such as nutrients or pollutants between the sediment and overlying water (Lerman 1977, Berner 1976, Aller 1978, Luedtke and Bender 1979, Emerson et al. 1984, Marinelli 1992). Fluxes can be an order of magnitude or more over those expected for molecular diffusion alone (Aller 1982, Benoit et al. 1991, Marinelli 1994), and can influence sediment chemistry by introducing oxygen to the sediments and removing sediment solutes like ammonia and sulfides (Aller 1982, Emerson et al.1984). Quantification of organism influence on flux is important for understanding nutrient dynamics and the fate of pollutants that enter the sediments (Luedtke and Bender 1979, Aller 1982, Emerson et al. 1984, Rutgers van der Loeff et al. 1984, Benoit et al. 1991, Marinelli 1994).

Despite extensive recent research on the effect of infaunal organisms on fluxes of dissolved chemicals across the sediment-water interface much remains to be learned. Most research has involved polychaetes or bivalves, and there is little information on how species-to-species interactions or particular combinations of organisms affect the flux (Aller and Yingst 1985, Marinelli 1992). There are many important infaunal organisms whose influences on fluxes have not been examined. One such group includes burrowing ophiuroids in the family Amphiuridae.

Amphiurid brittlestars live with their central disc burrowed several centimeters into muddy or sandy sediments, with one or more arm tips extended to the sediment surface for feeding and ventilation (Hyman 1955, Thomas 1962, Woodley 1975). Ventilation is performed by undulation of the arms and contraction or pumping of the disc (Hyman 1955, Woodley 1975, Pentreath 1971). Amphiurids have a world-wide distribution (Hyman 1955), and can be found from the intertidal zone to depths of several hundred meters in the oceans (Thomas 1962). They may occur in densities as high as 3000 individuals m^{-2} (Josefson 1995, Valentine 1991, Duineveld and Van Noort 1986, Bowmer and Keegan 1983) which has led to their use as dominants or co-dominants in the definition of many benthic marine communities (Thorson 1957). The species used in this study, *Microphiopholis gracillima* (Stimpson) (=*Amphipholis gracillima*, Thomas 1962, Hendler et al. 1995), occurs from Bermuda and Virginia to Brazil and is common along the southeastern coast of the United States (Singletary 1980). *M. gracillima* creates its burrows by removing sediment from depth and depositing it at the surface at burrow openings; and burrows are of a semi-permanent nature (Thomas 1962, Stancyk unpublished data).

The purpose of this investigation was to examine how *M. gracillima* influenced the flux of Li^{+1}, an inert tracer, from the sediment. We tested the hypotheses that a) the presence of brittlestars would increase the rate of Li^{+1}

transport through the sediments and b) the rate of Li^{+1} transport would increase as brittlestar density increased. Lithium is used because of its small size, which causes hydration of the ion and reduces its reactivity. Lithium ion is rarely exchanged for the common sodium ion in sediments (Cocco et al. 1978).

MATERIALS AND METHODS

Microphiopholis gracillima and sediment were collected from a subtidal mud flat in North Inlet, Georgetown, SC (37°20'N; 70°10'W) on 8 October 1995. In North Inlet *M. gracillima* has a density of 34-56 animals m^{-2} (Pape-Lindstrom et al. 1997). *M. gracillima*, separated from the sediment in the field by gently sieving, were placed in plastic bags with seawater for transport to Columbia, SC. In the lab, brittlestars were anesthetized with 35‰ $MgCl_2$ in a 1:1 solution with seawater, and 60 intact, healthy brittlestars were separated into four groups of 5 and four groups of 10 brittlestars. They were held in aquaria under experimental conditions until being placed into experimental cores.

In the lab, sediment was processed by wet sieving through a 1 mm mesh screen to remove large shells and macrofauna. The sediment was then mixed by hand, and two 13 liter (L) portions were separated and placed into plastic buckets to settle overnight. Overlying water was then removed, and 260 ml of a 10‰ Li^{+1} stock solution (stock solution was made by dissolving 61.08g of LiCl into a liter of water) was mixed into each bucket for a nominal concentration of 200 mg Li^{+1} L^{-1} sediment. After sitting for 24 h in the Li^{+1} solution, sediment was mixed again by hand and added to cores to create a 10 cm column of sediment in each core.

Sediment cores were made of clear acrylic plastic (inner diameter = 14.6 cm; wall thickness = 32 mm). False bottoms were created by placing 70m Nitex® screen between the core wall and a PVC ring approximately 2.5 cm tall, which held the screen tautly in place 2.5 cm above the base of the core (Wilson-Finelli 1996). Once the PVC ring and Nitex® screen were in place, two holes were drilled on opposite sides of the false bottom to allow a flow-through of a Li^{+1}-seawater solution. Two holes were also drilled on the upper portion of the core so that the overlying water could be flushed with natural seawater when samples were not being taken. A clear PVC stopcock was threaded into one hole to control the flow of seawater into the core. Plexiglass squares (7 in. x 7 in.) were affixed to the base of the cores with silicone sealant.

When the silicone had dried, twelve cores were set on a table with the false bottoms connected in a series by tubing, so that water could flow from the false bottom of one core to the next. After the twelve cores were assembled and connected with the tubing, they were partly filled with seawater, and air bubbles were removed from the screens creating the false bottoms. Once air bubbles were removed, silicone sealant was placed along the core edge at the false bottom, and a Gelman® extra-thick glass fiber filter (diameter 142 mm) was placed on top of the screen to keep sediment from falling into the false bottom. The seawater was then drained down to just above the filter, and the Li^{+1}-containing sediment was slowly added to each core under constant mixing until it reached the desired level. After settling for 24 h sediment was added or removed to create a sediment column of 10 cm. One liter (approximately 6 cm) of seawater was then added on top of the sediment for the overlying water. Cores then had aerators added to overlying water and were covered with plastic wrap to reduce evaporation. A 7 L reserve (open and unaerated) of a Li^{+1}-seawater solution was made up with 6.685 L of seawater and 0.315 L of 10‰ Li^{+1} stock solution for a nominal concentration of 450 ppm of Li^{+1}. With the cores connected in a series, the first core (core 1) had the Li^{+1}-seawater pumped into the false bottom from the reserve with a peristaltic pump at a rate of 11.9 ± 0.7 ml min^{-1}; the last core (core 12) had the Li^{+1}-seawater pumped (same pump) out of the false bottom back into the reserve. The chambers were completely set up and running on 26 October 1995.

Because Li^{+1} was added to the sediment, some time was necessary to allow the sediment to equilibrate and establish a concentration gradient with the reserve concentration of Li^{+1} at the sediment base (approximately 400 ppm) and a much lower concentration in the overlying water. The overlying water concentration of Li^{+1} was kept low by flushing the overlying water daily when samples were not being taken. Flushing of the overlying water was performed by running seawater from a 20 L carboy to each core individually through the inflow stopcock and out by way of a larger outflow opening into a bucket to be discarded. During times of sampling the overlying water was not flushed, but the seawater solution flowing through the false bottoms flowed continuously due to the small volume of the false bottoms (=500 ml). Cores did not have brittlestars during the period that the sediment was equilibrating. Samples of the overlying water were taken repeatedly between 8 November 1995 and 19 December 1995 to determine if a concentration gradient had stabilized.

Brittlestars were added to randomly designated cores on 22 December 1995. Treatments included controls (no brittlestars), 5 brittlestars per core (300 m^{-2}), and 10 brittlestars per core (600 m^{-2}) with four replicates each.

Because all cores were linked in a series, treatments were arranged in a randomized block design, so that each treatment occurred once per three cores, to control for a possible decrease of Li^{+1} from the reserve as water passed through the series of 12 cores.

Brittlestars were given 23 days to establish burrows before samples were taken. The temperature during sampling was 24.8 ± 0.8°C with the salinity at 33‰. On 14 January 1996 three 1 ml samples of the overlying water were taken from each core every 12 h for 120 h. Samples were then diluted to a volume of 20 ml with deionized water for analysis of Li^{+1}. Samples from cores 8 and 9 were rediluted due to high concentrations of Li^{+1}. Core 8 had a total dilution factor of 200; core 9 had a dilution factor of 80. The reserve was sampled every 24 h: three 1 ml reserve samples were diluted to a volume of 200 ml. All samples were analyzed for Li^{+1} with a Perkin-Elmer 5100PC flame atomic absorption spectrometer (Gieskes et al. 1991). The calibration curve was created from standards of 1, 2 and 3 mg $Li^{+1}L^{-1}$ with all samples diluted within this range. Linearity of the curve was assisted from the corresponding R^2, and calibration curves with an R^2 greater than 0.99 were used to determine Li^{+1} concentration.

Analysis of Li^{+1} concentration data was performed in SAS using an analysis of covariance with time as the covariate (SAS Institute Inc. 1982). The model was used to obtain the rate of change in the Li^{+1} concentration (slope) into the overlying water by treatment and the standard deviations around the treatment slope. Treatment slopes were then compared using 95% Bonferoni-corrected confidence intervals.

RESULTS

During the time that the sediment was relaxing, the reserve was losing water at a rate of approximately 100 ml day^{-1}. On 2 November, 6 L of a 400 ppm Li^{+1}-seawater solution (nominal concentration) were added to the reserve. The reserve lost a little more water, but stabilized in early December at a volume of 4.7 L. The reason for the loss of water is unknown, but may have been caused by evaporation in the cores, with the reserve water replacing the lost overlying water.

During the time that the flux was being measured, the reserve had a slow steady loss of Li^{+1} from 247 to 214 mg Li^{+1} L^{-1}. This corresponds to a loss rate of -0.24 mg $Li^{+1}L^{-1}$ h^{-1}. A mass balance calculation revealed that 95% of the Li^{+1} lost from the reserve was accounted for by the increase in the cores. The change in Li^{+1} concentration in the reserve had no significant effect on the model used in SAS.

Figure 1 shows the change of Li^{+1} over time in cores grouped by treatment. All Li^{+1} values were standardized by subtracting the mean Li^{+1} concentration in the overlying water of each core at time zero from all observations within a core. Actual starting and ending Li^{+1} concentrations are shown in Table 1. In general, the brittlestars increased the flux of Li^{+1} across the sediment-water interface by a factor of 2.5 - 3.5 times over the rate observed in the controls (0.29 to 0.21 vs. 0.08 mg Li^{+1} h^{-1}).

There was some variation within treatments. In the control cores, the flux of Li^{+1} varied from 0.02 to 0.15 mg Li^{+1} h^{-1}, and cores 6 and 7 had much higher fluxes than cores 2 and 11 (0.10 & 0.15 vs. 0.04 & 0.02 mg Li^{+1} L^{-1}), but they could not be eliminated as outliers (Figure 1).

Cores containing brittlestars had, on average, considerably higher fluxes than control cores. The 5 brittlestar treatment had a mean flux of 0.29 mg Li^{+1} h^{-1}. Core 9 was unusual, with an increasing slope in the last half of the experiment and an extremely high flux of 0.47 mg Li^{+1} h^{-1}. When core 9 is excluded, the mean flux drops from 0.29 to 0.22 mg Li^{+1} h^{-1} (Figure 1). The 10 brittlestar treatment had a mean slope of 0.21 mg Li^{+1} h^{-1}. Three of the cores (5, 8, and 12) grouped together very nicely, but core 1 had a slightly higher flux (Figure 1).

Figure 2 is a graph of the mean treatment slopes. Because of the unusual size and shape of its slope, core 9 was excluded from this graph and the rest of the analysis. Figure 2 shows that the brittlestars caused a 2.7-fold increase in the flux of Li^{+1} across the sediment-water interface. When 95% Bonferoni-corrected confidence intervals are compared, there is a significant difference in the control from the brittlestar treatments, but no difference when the density of brittlestars is changed from 300 to 600 brittlestars m^{-2} (Table 1).

DISCUSSION

This study demonstrated that burrowing brittlestars had a significant effect on the flux of Li^{+1} across the sediment-water interface. Brittlestars in natural densities significantly increased the rate of Li^{+1} transported out of the sediment by 2-3 times over controls (0.21 or 0.22 vs. 0.08 mg Li^{+1} h^{-1}; Figure 2). This significant increase in Li^{+1} transport falls within reported values of organism effects on fluxes across the sediment-water interface (Table 2).

One explanation for the unexpected variation among control cores is that the sediments were not fully equilibrated in cores 6 and 7. Another possible explanation for the high fluxes in control cores 6 and 7 could be the existence of slight variations in the core height. The PVC rings used to create the false bottoms were cut using a band saw, and the rings were not exactly the same height. This caused some of the cores to sit slightly lower than others when sediment

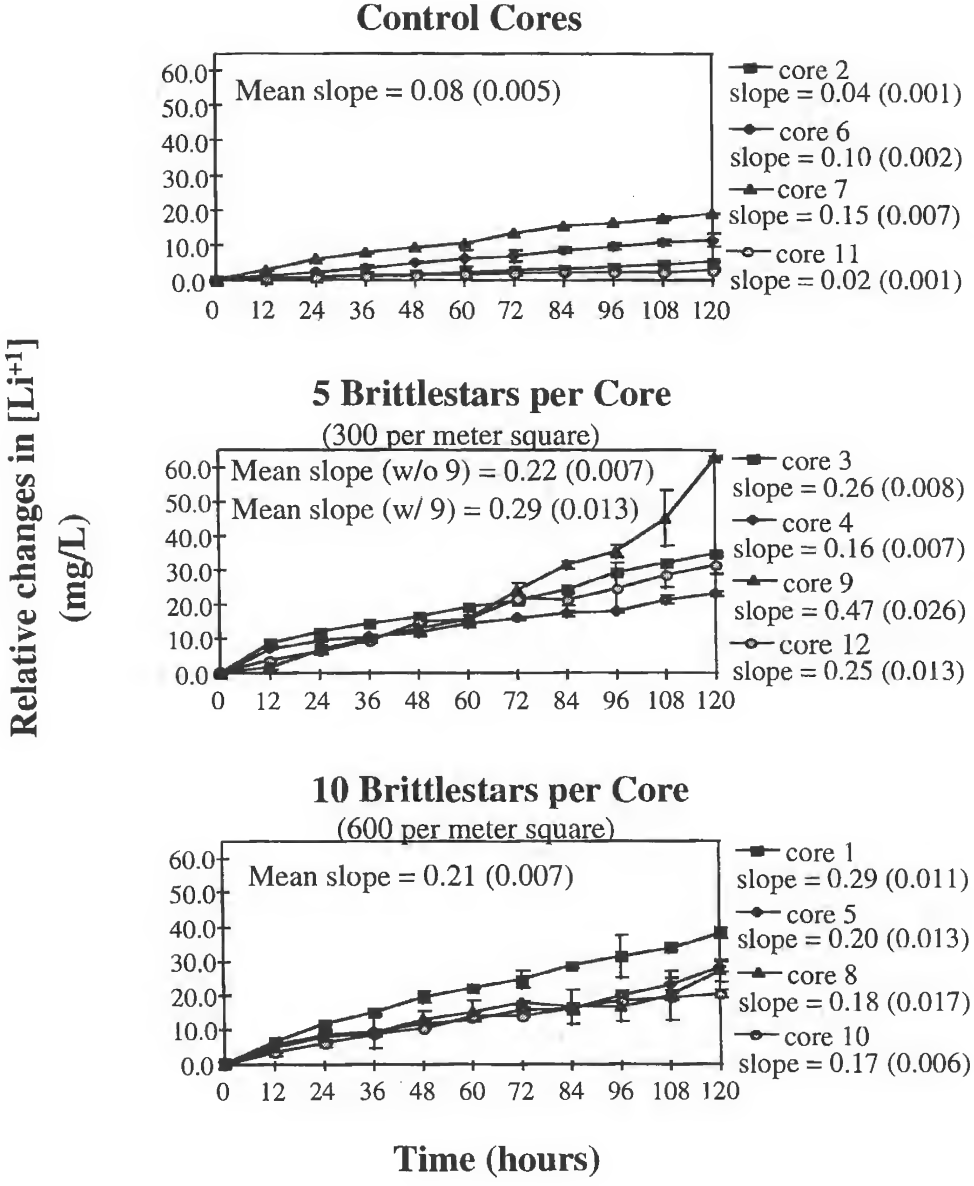

Figure 1. The relative change in concentration of Li^{+1} in the overlying water over time in cores grouped by treatment. Values were standardized by the subtraction of the Li^{+1} concentration at time zero for each core. Error bars indicate the standard deviation of the three replicate measures at each sampling period. The slope for each core is given in the legend as mg Li^{+1} h^{-1} (standard deviation).

TABLE 1

Relevant values, with cores grouped by treatment. The lithium flux rate of the cores with their associated standard error are given. A negative flux rate means that lithium was fluxed out of the sediment. The starting and ending Li^{+1} concentrations (mg/L) for each core are listed. Treatment mean flux is given with the 95% Bonferoni-corrected confidence interval.

Controls	Flux rate of Li^{+1} (mg/hr)	Std. Err.	Starting-Ending Li^{+1}concentration	Porosity
Core 2	-0.04	0.001	2.8-8.2	0.45
Core 6	-0.10	0.002	6.7-18.0	0.45
Core 7	-0.15	0.007	18.0-36.8	0.47
Core 11	-0.02	0.001	9.5-12.5	0.43
Average	-0.08	0.005		
Bonferoni	-0.07-(-0.09)			
Five brittlestars				
Core 3	-0.26	0.008	8.3-43.0	0.46
Core 4	-0.16	0.007	8.5-31.5	0.51
Core 9	-0.47	0.026	29.1-91.5	0.46
Core 12	-0.25	0.013	29.7-60.7	0.47
Average	-0.29	0.013		
Average				
Without core 9	-0.22	0.007		
Bonferoni	-0.20-(-0.24)			
Ten brittlestars				
Core 1	-0.29	0.011	24.8-62.4	0.46
Core 5	-0.20	0.013	13.3-41.3	0.46
Core 8	-0.18	0.017	68.0-95.3	0.46
Core 10	-0.17	0.006	19.1-39.3	0.47
Average	-0.21	0.007		0.46
Bonferoni	-0.19-(-0.23)			

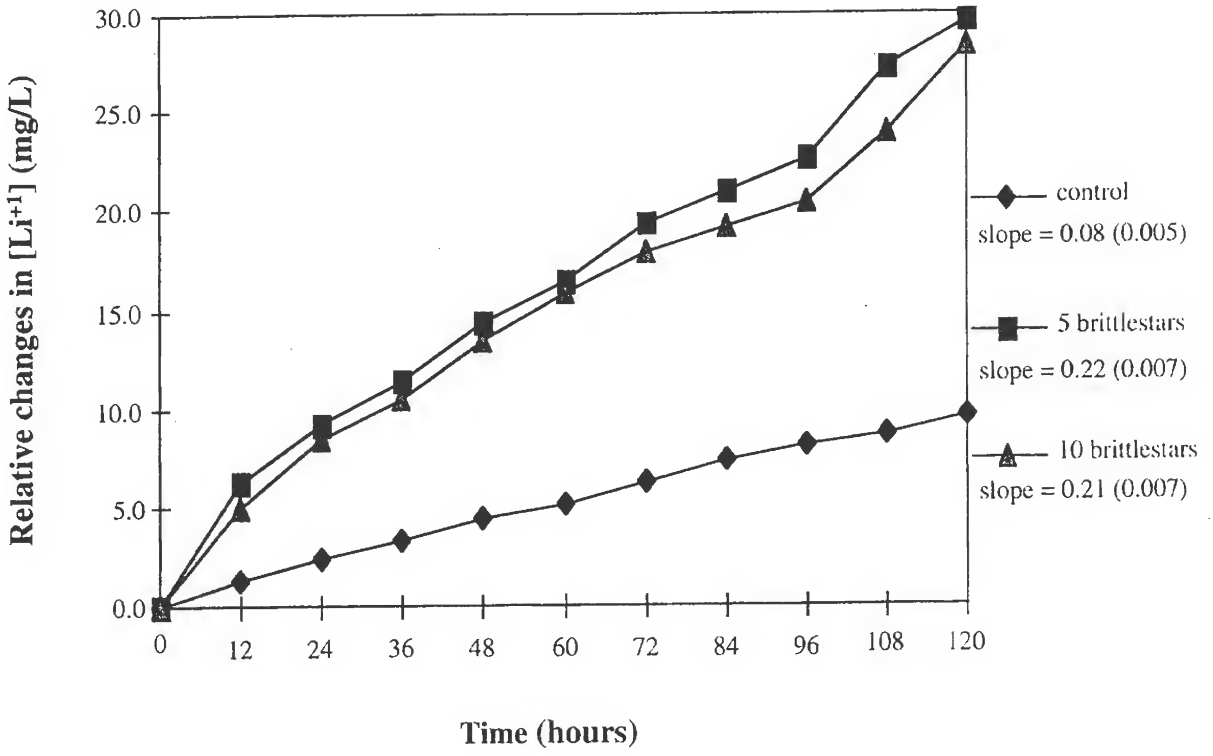

Figure 2. Average slopes for all treatments based on the values standardized by the subtraction of the Li^{+1} concentration at time zero for each core. The slope for each treatment is given as mg Li^{+1} hr^{-1} (standard deviation)

TABLE 2

Comparison of literature values of measured flux over flux predicted by molecular diffusion. Controls *in situ* were not always possible, so that the observed flux due to organisms was compared to the flux-based calculations of molecular diffusion in sediments (see Berner 1976, Lerman 1977 and Aller 1982 for discussions on calculating fluxes across the sediment-water interface). Note that differences in flux rates will vary depending on the chemistry of the compound or tracer studied (modified from Benoit et al. 1991).

Laboratory or Field Setting	Species or Location	Observed Flux/ Predicted Flux	Source
Laboratory	*Yoldia limatula*	1.4	Aller 1978
Laboratory	*Heteromastus filiformis, Macoma balthica, Tellina texana*	2-5	Aller and Yingst 1985
Field	Po delta lagoon, Italy	3-20	Barbanti et al. 1992
Field	Mystic River, CT, USA	13-30	Benoit et al. 1991
Field	Puget Sound, WA, USA	3-5	Emerson et al. 1984
Field	Gulf of Mexico, TX, USA	8-10	Filipek and Owen 1980
Field	Long Island Sound, CT, USA	5	Goldhaber et al. 1977
Field	Hudson River estuary, NY, USA	2-3	Hammond et al. 1977
Laboratory	*Eupolymnia heterobranchia*	≤2.4	Marinelli 1994
Field	Buzzards Bay, MA, USA	0.2(winter) 8 (summer)	Martin and Sayler 1987
Field	Narragansett Bay, RI, USA	6	McCaffrey et al. 1980
Field	Gullmarsfjorden, Sweden	2-10	Rutgers van de Loeff et al. 1984
Laboratory	*Microphiopholis gracillima*	5-10	This study

column height and water volume were held constant. A core that sat lower than other cores would have an increased head pressure from the other cores due to their higher water level. Because the cores were interconnected through the false bottoms, the head pressure would exert a pressure at the base of the sediment column, forcing the Li^{+1}-seawater solution to be pushed up into the sediments. With no organisms to remove the forced influx of Li^{+1} from the sediment, the core would not be at steady state. This problem could be solved by using a multi-channel peristaltic pump so that each core would have a separate push/pull system, thus removing variance due to interconnections.

The flux of Li^{+1} increased dramatically in the overlying water in core 9 (a 5 brittlestar treatment) during the last half of the experiment (Figure 2). In this case, one or more brittlestar(s) probably established a burrow at the base of the sediment column, setting up a channel for Li^{+1} to pass easily from the false bottom to the overlying water. *Microphiopholis gracillima* commonly burrows to a depth of 10 cm (Singletary 1980), which was the height of the sediment columns used in this experiment, but we have seen them extend arm burrows to 20 cm in a core with a 20 cm sediment column.

Interestingly, the doubling of density from 300 to 600 brittlestars m^{-2} did not change the rate that Li^{+1} was moved across the sediment-water interface (5 brittlestars, 0.22 mg Li^{+1} h^{-1}; 10 brittlestars, 0.21 mg Li^{+1} hr^{-1}; Figure 2). This is in contrast to two *in situ* studies, Rutgers van der Loeff et al. (1984) and Barbanti et al. (1992), which reported a positive relationship between the density of organisms and the flux of nutrients across the sediment-water interface.

Although an increase in the transport of Li^{+1} was expected with increasing density of brittlestars, the fact that there was no difference was not a complete surprise. In examining infaunal effects on sediment dynamics, Aller (1982) created a 3-dimensional model based on a centrally irrigated burrow and the surrounding sediment. The model showed that the distance between burrows affected the flux of solutes across the sediment-water interface and predicted that crowding in high densities would reduce the irrigation requirements of infauna due to the lower concentration of sediment-derived solutes such as ammonia in the surrounding sediments. Based on Aller's model, the brittlestars in this experiment could have benefited from the irrigation of the other brittlestars, thereby reducing each individual's need for ventilation at higher densities. The results imply that there is a threshold density above which the flux would remain constant even when brittlestar numbers are increased. A test of this hypothesis will require data on densities below 300 m^{-2}.

There are a number of areas where future research is needed to examine the role of the benthos on fluxes across the sediment-water interface. In particular, the existence of a threshold density above which fluxes are stabilized could have a significant impact on flux models of dissolved chemicals in areas populated by infauna such as burrowing brittlestars. Predictions of nutrient fluxes, nutrient production rates and fate of pollutant transfers could be affected (Aller 1982, Emerson et al. 1984, Marinelli 1992). Emerson et al. (1984) suggested that infaunal organisms could affect the mobility of trace metals (Cu and Cd) by the removal of sulfides from the sediment with irrigation of the burrows. But environmental managers need to know if such processes vary with infaunal density or not.

In conclusion, this experiment showed that amphiurid brittlestars significantly increased the flux of Li across the sediment-water interface 2.75 times over control cores. Increasing the density from 300 to 600 brittlestars m^{-2} had no effect on the flux of Li^{+1}, leading to a hypothesis that a threshold density exists beyond which higher densities will not increase the rate that solutes are moved from the sediments.

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Occurrence of a Synchronous Hermaphroditic Striped Mullet, *Mugil cephalus*, from the Northern Gulf of Mexico

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OCCURRENCE OF A SYNCHRONOUS HERMAPHRODITIC STRIPED MULLET, *MUGIL CEPHALUS*, FROM THE NORTHERN GULF OF MEXICO

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Abstract A synchronous hermaphroditic striped mullet, *Mugil cephalus*, was captured offshore of Southwest Pass, Louisiana on 6 December 1996 during the commercial roe mullet fishery harvest. The fish measured 412 mm FL, weighed 824 g and was determined to be 4 years old by otolith analysis. Gross examination of the gonads revealed four lobes: right and left ovaries and right and left testis which represents a unique occurrence among hermaphroditic fish. All lobes ended in a common sperm duct/oviduct with the exception of the left ovary which had no oviduct. Both ovaries contained vitellogenic oocytes and both testis had freely running spermatozoa. Histological examination showed many oocytes undergoing final oocyte maturation, the presence of some post ovulatory follicles and lobules full of tailed spermatozoa. There was no evidence of the intermingling of sperm and oocytes within the gonad. The capture of this fish on the spawning grounds and the advanced stage of both ovarian and testicular development suggests spawning probably would involve the release of both oocytes and spermatozoa.

Introduction

Striped mullet, *Mugil cephalus*, are distributed worldwide in most coastal and estuarine waters of tropical and subtropical seas (Render et al. 1995). Striped mullet support an important commercial fishery in the Gulf of Mexico and the South Atlantic Bight where they are harvested for both their flesh and roe. The recent expansion of the striped mullet fishery in Alabama, Mississippi and Louisiana is directly related to the increased commercial harvest of seasonally available (October-January) "roe mullet" in the northern Gulf of Mexico (Leard et al. 1995).

The reproductive biology of striped mullet in the northern Gulf of Mexico has recently been documented (Render et al. 1995). Gonadal maturation of both males and females begins in the estuaries in September, while spawning occurs offshore from November through early January. Striped mullet are isochronal spawners, although batches of oocytes may be hydrated and spawned on successive days due to size limitations in the body cavity (Render et al. 1995). Chang et al. (1995) determined that striped mullet are an undifferentiated gonochorist species, with all individuals completing gonadal differentiation by 18 months.

Hermaphroditism is a relatively common reproductive strategy among teleosts and can be divided into three basic categories; protogyny, protandry and synchronous hermaphroditism (Sadovy and Shapiro 1987). Protogynous hermaphrodites function first reproductively as females and then change sex to become reproductively functioning males; protandrous hermaphrodites are first males and then become sexually functioning females. Synchronous hermaphrodites are individuals that can function at the same time of life as both male and female.

In addition to normal hermaphroditism, in which all individuals within a species are hermaphroditic, there have been many reports of abnormal hermaphroditism (Atz 1964), in which hermaphroditic individuals of a normally gonochoristic species have been found. There have been several scattered reports of hermaphroditism in the Mugilidae, all based on one or two specimens. Ovotestes have been reported in *Mugil chelo* (Orlandi as cited in Moe 1966) and *M. platanus* (Andrade-Talmelli et al. 1994). Hermaphroditism in *M. cephalus* has been documented three times (Stenger 1959; Moe 1966; Thompson et al. 1991). The purpose of our report is to describe the occurrence of an unusual synchronous hermaphroditic striped mullet from the northern Gulf of Mexico, which differs substantially from previously described hermaphroditic mullet.

Materials and Methods

A hermaphroditic striped mullet was captured on 6 December 1996 during commercial roe mullet harvesting operations conducted offshore of Southwest Pass, LA. The specimen was among thousands of mullet taken in a 16,000 kg pair-trawl haul that was iced on board the fishing vessel and subsequently transported to Clark Seafood Company, Pascagoula, MS for processing. The hermaphroditic specimen was detected on 9 December 1996 during routine roe mullet biological sampling conducted at the Clark facility and was one of 45 roe

mullet randomly selected and sampled on that date. Fork length (FL, mm) and total weight (TW, g) of all 45 mullet were recorded, and gonads were removed and weighed to the nearest 0.1 g.

The hermaphroditic specimen was brought to our laboratory for further examination and the gross morphology of the fresh gonads was described. We excised the gonads from the specimen but did not detach male from female elements. Gonads were measured for total length (mm) and greatest width (mm), blotted dry, weighed (total combined weight of ovaries and testes) and preserved whole in 10% neutral buffered formalin. The weight of the gonads was expressed as a function of total body weight by a gonadosomatic index (GSI) (DeVlaming et al. 1982):

GSI = (gonad weight/total fish weight-gonad weight) x 100

We measured the diameter of ten of the most advanced stage oocytes (fresh) from the anterior and medial regions of the left and right ovaries as well as from the posterior region of the left ovary. Oocyte measurements were made to the nearest 0.001 mm using a binocular dissecting microscope with an image analysis system at 60x magnification. Mean diameter of leading stage oocytes was calculated for each region.

We estimated the specimen's age using sagittal otoliths, which were removed, cleaned with distilled water, and air dried. The left sagitta was embedded in Spurr (Secor et al. 1992) and sectioned through the core at 0.3-mm intervals along a transverse, dorso-ventral plane using a Buehler Isomet low-speed saw. Three sections were mounted on a microscope slide with CrystalBond 509 adhesive, sanded with wet 600- and 1500-grade sandpaper and polished on a felt wheel with 0.3μ alumina micropolish. The opaque bands occurring from the otolith core to the outer margin were counted at 20-40x magnification using transmitted light.

Small (1 cm^3) pieces of tissue were removed from the preserved ovarian and testicular tissues for histological analysis. Additionally, samples from areas where ovarian and testicular tissue appeared joined were taken. Tissue samples were dehydrated, cleared and embedded in paraffin following standard histological techniques. The tissues were sectioned at 5 μm, mounted on slides and stained with hematoxylin and eosin prior to histological inspection. Oocyte, atretic and post ovulatory follicle (POF) stages were classified following Hunter and Macewicz (1985a, b).

RESULTS

An external inspection of the specimen indicated the fish was in good condition. The specimen measured 412 mm FL and weighed 834 g TW. The other specimens of striped mullet (male, n = 32; female, n = 12) included in the random sample ranged from 289-468 mm FL (mean, 362 mm) and 300-1,372 g TW (mean, 626 g). The length of our specimen was greater than that of 81% of the males (mean, 258 mm) and 70% of the females (mean, 385 mm) in the sample, and its weight was greater than that of 88% of the males (mean, 588 g) and 58% of the females (mean, 794 g).

Internal observation revealed paired, well-developed ovaries and testes which occupied most of the body cavity (Figure 1). The bright yellow ovaries and the white testes appeared as distinctly individual organs, albeit uniquely juxtaposed within the body cavity. A generalized gross morphological description of the gonads follows.

Left ovary: The ovary measured 110 mm in length and 38 mm at its greatest width, approximately twice the greatest width of the right ovary. With the exception of the anterior-most portion, the entire left ovary was devoid of an ovarian wall (tunica albuginea; Figure 1) and appeared as a thick gelatinous mass of exposed, well-developed oocytes. The absence of an ovarian wall and the large egg mass gave the ovary a ruptured appearance. Only the anterior portion of the ovary with the tunica albuginea was attached to the dorsal wall of the fish. The remainder of the ovary was loosely adhered only to the left testis by mesenteries. The ovary ended abruptly 35 mm from the genital pore, and there was a conspicuous absence of an oviduct.

Right ovary: The ovary measured 135 mm in length and 22 mm in width at its anterior region. Approximately 50 mm from the anterior tip the ovary decreased in width to 10 mm and continued posteriorly as an ever-narrowing, bright yellow tube. The entire ovary was covered by tunica albuginea and was attached by mesenteries to the dorsal wall along its complete length. An oviduct extended to the region of the genital pore.

Left Testis: The testis measured 142 mm in length and 21 mm at its greatest width. The extremely narrow (4 mm) anterior region of the lobe was firmly attached to the left ovary (Figure 1). A small area of the ribbon-shaped anterior region located 20 mm from the anterior tip was so overlain with left ovarian tissue that the testis erroneously appeared to terminate at that point. The posterior-most 40 mm of the testis was attached to the dorsal wall, however, the remainder of the testis was attached by mesenteries to the left ovary only. A sperm duct extended to the region of the genital pore.

Right testis: The testis was neither as long (103 mm) nor as wide (14 mm at its greatest width) as the left testis. The organ was affixed to the dorsal wall (at attachment sites adjacent to those of the right ovary) along its entire length and was loosely joined by mesenteries to the mid-

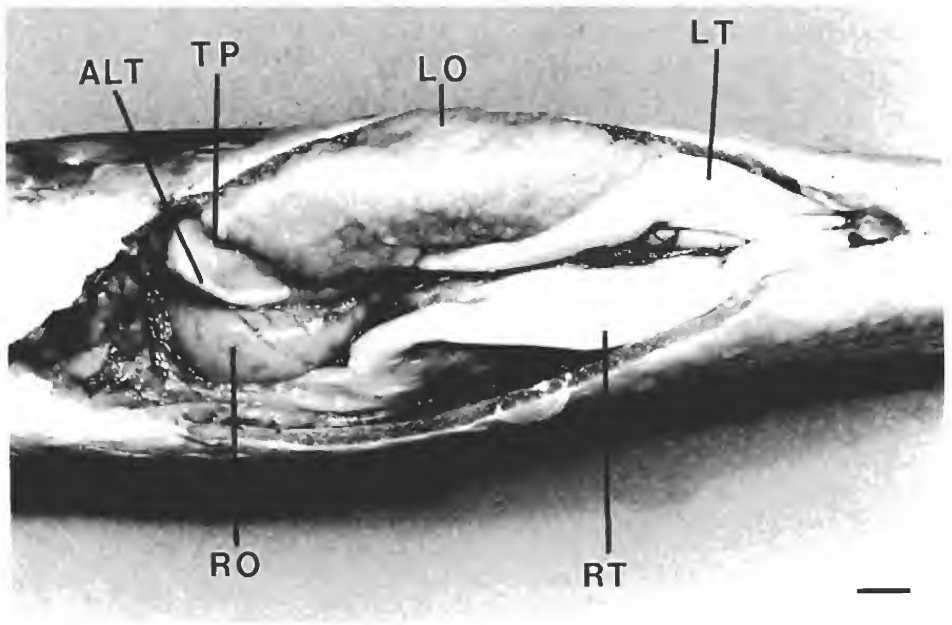

Figure 1. Paired gonads of the synchronous hermaphroditic striped mullet, *Mugil cephalus*. LO, left ovary; RO, right ovary; LT, left testis; RT, right testis; TP, termination point of tunica albuginea (ovarian wall) on left ovary; ALT, anterior region of left testis. Scale bar = 10 mm.

region of the right ovary. A sperm duct extended to the region of the genital pore.

Although the ovaries and testes were closely aligned within the body cavity, the gonads were well delineated and the germinal tissues were, in most instances, separated by mesenteries. There was no apparent intermingling of male and female tissues. The posterior region of each testis and the right ovary were loosely joined by mesenteries anterior to the genital pore. Each sperm duct and the right oviduct joined to form a common duct which terminated at the genital pore.

The total weight of the specimen's gonads (ovaries and testes) was 98.6 g, with a GSI value of 12.0. Mean GSI values for the 32 males and 12 females in the sample were 13.3 (± 0.75, SEM) for males and 15.7 (± 1.89) for females, while mean GSI calculated for specimens similar in length (FL range, 394–419 mm) to the hermaphroditic fish were 9.8 (± 1.01) for males (n = 7) and 16.7 (± 4.19) for females (n = 3).

Each testis from the hermaphroditic specimen was sliced open and milt ran freely from the incisions. Observation of the fresh milt under a compound microscope revealed well-developed sperm. Macroscopic observations of the ovaries revealed that large, yolked oocytes in the migratory nucleus phase dominated the samples from all regions examined; the mean diameters of the leading stage oocytes are shown in Table 1. The posterior region of the left ovary also contained a substantial number of medium-size, yolked oocytes with a mean diameter of 0.334 mm.

TABLE 1

Mean oocyte diameters (mm) from selected regions in the left and right ovary of a hermaphroditic striped mullet, *Mugil cephalus*.

Ovarian Region	Left Ovary	Right Ovary
Anterior	0.670	0.673
Medial	0.682	0.643
Posterior	0.642	Not Collected

Histological inspection of ovarian tissue from both the right and left lobes showed this specimen was an isochronal spawner undergoing final oocyte maturation, as evidenced by many oocytes in the migratory nucleus phase (Figure 2A). Some yolked oocytes from both lobes were in ß-stage atresia (Figure 2A). Three 24-h post-ovulatory follicles (POF) were found in the anterior portion of the right ovary and two 24-h POF were found in the mid section of the right ovary; no other ovarian sections showed evidence of recent spawning.

Histological inspection of testicular tissue from both the right and left lobes showed lobules full of spermatozoa as well as spermatozoa in the sperm ducts (Figure 2B). Late stages of spermatogenic activity (secondary spermatocytes and spermatids) occurred in cysts in the periphery of the testis. The testicular walls appeared unusually thick in this specimen, although there was no evidence of abnormal morphology or cellular structure.

Tissue samples taken from areas where ovarian and testicular tissues overlapped showed thick testicular walls, no interconnections between the ovaries and testis and no intermixing of sperm and oocytes (Figure 2C). Areas where ovaries and testes appeared upon gross examination to be fused separated into distinct ovarian and testicular tissues after histological processing; no evidence of tearing or destruction of the testicular wall was apparent.

Otolith analysis revealed three distinctive opaque bands with considerable growth of the otolith beyond the last band. Based on age validation of striped mullet from Louisiana (Thompson et al. 1989) and time of first annulus formation (Thompson et al. 1991), we estimate an age of four years for the specimen. .

DISCUSSION

The occurrence of fully developed ovaries and testes and histological evidence that spawning was eminent (final oocyte maturation and spermatozoa in the sperm duct) leads us to conclude that this mullet is a synchronous hermaphrodite, although with several notable differences from normal synchronous hermaphrodites. Sadovy and Shapiro (1987) state that all normal synchronous hermaphrodites have an undelimited gonad, meaning there is no membrane or connective tissue separating the male and female structures. Thus, two gonadal lobes, each containing testicular and ovarian tissues, is the norm with synchronous hermaphrodites. In no cases are normal synchronous hermaphrodites reported to have four lobes of gonadal tissue.

The specimen we examined is also unique among abnormal hermaphrodites. The majority of hermaphroditic individuals of gonochoristic species have ovotestes (Atz 1964) or occasionally ovaries and an ovotestis (Pinto 1952; Holliday 1962 as cited in Atz 1964), and many have been reported to contain mature oocytes and spermatozoa simultaneously. Of the five previously published cases of hermaphroditism in mullets (Stenger 1959; Moe 1966; Orlandi as cited in Moe 1966; Thompson et al. 1991; Andrade-Talmelli et al. 1994), all involved a one or two lobed ovotestis. Moe (1966) and Orlandi (as cited in Moe 1966) observed the gonads of three mullet that were

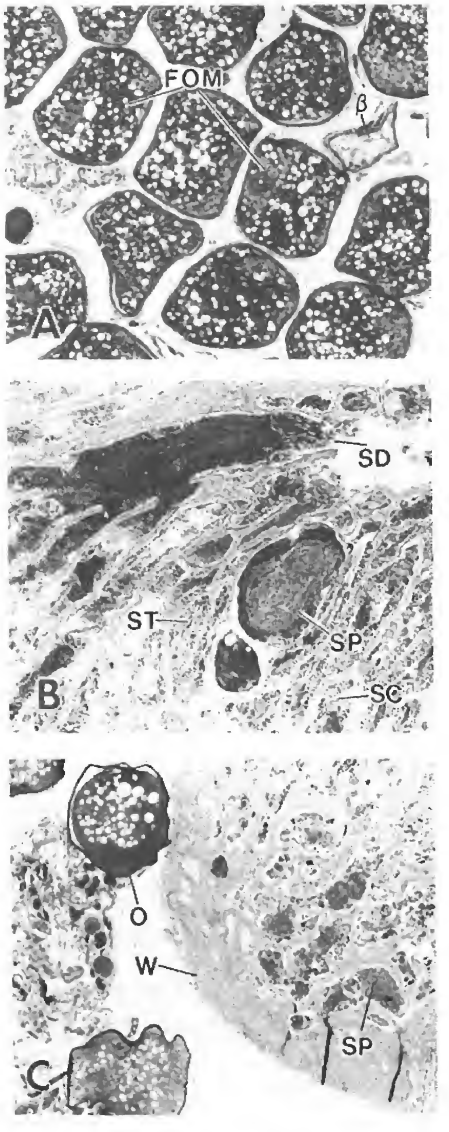

Figure 2. Histological sections from the gonads of the hermaphroditic striped mullet, *Mugil cephalus*. A. Section from the left ovary showing isochronal oocyte development with some oocytes undergoing final oocyte maturation (FOM). ß, yolked oocyte in ß-stage atresia. 66X. B. Section from the left testis in late stages of spermatogenesis showing secondary spermatocytes (SC), spermatids (ST) lobules full of spermatozoa (SP) and spermatozoa in the sperm duct (SD). 64X. C. Section showing separation of left ovarian and testicular tissue at the anterior end which appeared to be fused upon gross observation. Note the thick testicular wall (W) and that there is no intermingling of oocytes (O) and spermatozoa (SP). 66X.

primarily ovarian in nature, but contained patches of testicular tissue. Histological examination of one *M. cephalus* ovotestis revealed mesenteries separating the ovarian and testicular tissues and simultaneous development of both oocytes and sperm (Moe 1966). Stenger (1959) reported a *M. cephalus* gonad that appeared ovarian on gross examination, but contained a section with tailed spermatozoa upon histological inspection.The gonads of two hermaphroditic specimens of *M. platanus* appeared to be predominately testicular with small patches of ovarian tissue (Andrade-Talmelli et al. 1994). In one of those specimens, the ovarian and testicular tissues were separated by mesenteries and in the other, mature oocytes and tailed spermatozoa were freely mixing within the gonad. Most recently, Thompson et al. (1991) reported a four-year-old *M. cephalus* with two gonadal lobes containing a mosaic of ovarian and testicular tissues in an advanced stage of reproductive development. Finally, an unpublished report of a hermaphroditic *M. cephalus* captured from the Neuse River, NC in October 1982 described a two lobed gonad, predominately testicular, with large patches of ovarian tissue containing yolked oocytes on the anterior portion of each testis (S.W. Ross, North Carolina National Estuarine Research Reserve, Wilmington, NC, pers. comm.). In no previously cited cases have distinctively separate ovarian and testicular gonads been reported in a hermaphroditic mullet.

Hermaphroditic striped mullet are rarely encountered in the northern Gulf of Mexico. A major processor of roe mullet in the northern Gulf of Mexico could not remember a single instance of hermaphroditism in striped mullet during his many years of processing thousands of mullet for the roe market, nor could he recall that other mullet processors within the region had ever mentioned such an occurrence to him (Mr. Phil Horn, Clark Seafood Company, Pascagoula, MS, pers. comm.). We agree that such an occurrence is rare, since it is unlikely that the distinctively unique condition would go unnoticed (or unreported) by seafood plant employees engaged in the processing of roe mullet. Furthermore, fisheries personnel with the Gulf Coast Research Laboratory doing routine biological sampling have never encountered a striped mullet exhibiting hermaphroditic characteristics. Reported occurrences of hermaphroditic *M. cephalus* from the Gulf of Mexico are rare in the published literature. Stenger (1959) described one specimen from Florida waters and Thompson et al. (1991) discussed one specimen caught nearshore in Mississippi. Moe (1966) reported on two specimens from the Gulf waters off Florida which commercial fishermen had saved as a curiosity, suggesting the rarity of the occurrences. Additionally, Moe (1966) commented that no other incidents of hermaphroditism in striped mullet from Florida could be documented despite extensive dialogue with biologists and fish dealers. Hermaphroditic striped mullet are also rare in the South Atlantic Bight; no cases have been reported in the literature although one specimen was captured in the Neuse River, NC (S.W. Ross, pers. comm.).

The abnormal hermaphroditic condition of our specimen did not appear to affect its growth. The age of the hermaphroditic fish (4 years) agreed favorably with the ages (3-5 years) of ten other striped mullet from the random sample which were similar in size to the study specimen. Additionally, our specimen was only slightly longer than the mean fork lengths reported for Louisiana striped mullet with three and four annuli on their otoliths (Thompson et al. 1989).

The GSI value of our hermaphroditic specimen was similar to GSIs of the normal, gonochoristic striped mullet collected in the same sample. Additionally, the GSI value of our specimen (12.0) was similar to the GSI of the North Carolina hermaphroditic striped mullet (12.9; S.W. Ross, pers. comm.). However, Render et al. (1995) reported a GSI value for Louisiana females captured in November and December of approximately 23.0 for the mean length interval of 410-420 mm FL, a value considerably larger than that for our specimen; GSI values were not reported for males larger than 380 mm. While striped mullet GSI values can vary in the same month among years (Render et al. 1995), we feel the discrepancy in GSI values between the Louisiana and Mississippi fish is related to differences in location of capture. The Louisiana striped mullet were captured in estuarine/coastal areas at the start of their spawning migration (Render et al. 1995), while our specimen was captured offshore on the spawning grounds. Render et al. (1995) reported no histological evidence of final oocyte maturation (FOM) or POF in the striped mullet they examined, suggesting spawning had not yet commenced, resulting in maximal GSI values. The striped mullet that we examined was in a more advanced stage of ovarian development than any examined by Render et al. (1995), as evidenced by the large numbers of oocytes undergoing FOM. Additionally, the presence of ß-stage atresia, unreported by Render et al. (1995) in developing ovaries, suggests some fully mature oocytes had not undergone hydration and spawning. Finally, the presence of POF in the right ovary of our hermaphroditic striped mullet suggests spawning in the previous 24 hours, which would result in a reduction of GSI.

Although oocyte development in our specimen appeared to be progressing normally in both ovaries and was in the FOM stage, eggs could not have been released in a normal

fashion from the left ovary due to the lack of an oviduct. Histological evidence of recent oocyte hydration and spawning in this specimen (i.e., POF) may explain the ruptured appearance of the left ovary; perhaps the dramatic increase in ovarian mass during hydration and the inability to release the oocytes through an oviduct resulted in the rupture of the tunica albuginea. It is unknown if this fish would have survived the spawning season with a ruptured left ovary. However, the size and age of the fish suggests this was not its first spawning season (Render et al. 1995; Leard et al. 1995; Thompson et al. 1991), raising questions regarding gonadal condition and maturity in the previous year.

Although the occurrence of abnormal hermaphroditism has been documented in a variety of species (Atz 1964), there has never been a satisfactory answer to how this unusual situation develops. The recent interest in endocrine disrupters, as well as the experimental induction of ovotestes in the medaka (*Oryzias latipes*) following exposure to 4-nonylphenol (Gray and Metcalfe 1997), suggests that environmental exposures to estrogenic compounds may explain some reported cases of hermaphroditism. However, the endocrine disrupter explanation would only apply to abnormal hermaphrodites with ovotestes, which is clearly not the case for the striped mullet reported here. Given the rarity of the type of hermaphroditism reported here, we can only conclude that this fish received "mixed messages" during gonadal differentiation, resulting in the development and eventual maturation of separate ovaries and testes.

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Food Habits and Dietary Overlap of Newly Settled Red Drum (*Sciaenops ocellatus*) and Atlantic Croaker (*Micropogonias undulatus*) from Texas Seagrass Meadows

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FOOD HABITS AND DIETARY OVERLAP OF NEWLY SETTLED RED DRUM (*SCIAENOPS OCELLATUS*) AND ATLANTIC CROAKER (*MICROPOGONIAS UNDULATUS*) FROM TEXAS SEAGRASS MEADOWS

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ABSTRACT Food habits and dietary overlap of newly settled larval and juvenile red drum and Atlantic croaker were examined during the period when the two species co-occur in seagrass nurseries. A total of 274 red drum (4.00 - 19.99 mm SL) and 205 Atlantic croaker (8.00 - 17.99 mm SL) were used for this analysis. Of the red drum stomachs examined, 8.4% were empty while 28.8% of Atlantic croaker stomachs contained no food. Major prey items identified for both species were calanoid copepods, harpacticoid copepods and mysid shrimp across all size classes. Ontogenetic trophic niche shifts were detected for red drum and Atlantic croaker. Type and quantity of food ingested by red drum were similar across all stations (Aransas Bay Station: 1H, 2T and 3H) examined. Atlantic croaker ingested the same types of prey at all stations, but contained varying quantities of food throughout the study area. In general, high dietary overlap was observed between red drum and Atlantic croaker with most overlap values (Schoener's index) exceeding 70%.

Introduction

Red drum (*Sciaenops ocellatus*) spend most of their adult lives offshore and migrate to tidal passes to spawn in late August through mid-November, whereas adult Atlantic croaker (*Micropogonias undulatus*) occupy gulf coastal waters and congregate offshore to spawn in early October through February (Johnson 1978). Pelagic larvae of both species are transported by currents through tidal inlets and into nursery habitats in bays and estuaries (Rooker et al. 1998). Consequently, larval and juvenile red drum (4 - 20 mm SL) occupy seagrass beds from late September to early December, while larval and juvenile Atlantic croaker (8 - 18 mm SL) are found in seagrass beds from early October to February (Holt et al. 1983, Rooker et al. 1998). Both species concurrently occupy seagrass beds in November at similar sizes.

Conspecifics and morphologically similar species (i.e., confamilials) occupying similar habitats can potentially compete for food particularly during times when fish densities are high and prey is scarce. Intraspecific and interspecific competition among larval fishes can reduce growth rates, which in turn, may increase early-life stage mortality due to starvation or predation (Houde 1987). Therefore, it is important to understand the trophic relationships of early life stages.

Fishes change resource (food) use throughout the course of their lives, especially during larval and juvenile stages. Such ontogenetic niche shifts may divide size-structured populations into ecologically distinct stages based on diet (Olson 1996). Duration of stages and transition among stages has the potential to minimize intraspecific competition for food.

Although several studies have addressed food habits of these two species separately (Bass and Avault 1975, Chao and Musick 1977, Oversteet and Heard 1978, Steen and Laroche 1983, Govoni et al. 1983, Currin et al. 1984, Govoni et al. 1986, and Peters and McMichael 1987), no dietary overlap analysis has been conducted on newly settled red drum and Atlantic croaker. The primary aim of this study was to obtain an understanding of the trophic dynamics of newly settled larval and juvenile red drum and Atlantic croaker occurring in seagrass habitat. Specific objectives were to: 1) quantitatively describe the diets of larval and juvenile red drum and Atlantic croaker; 2) determine ontogenetic changes in diets of the two species; 3) determine if diet varies across different sites and habitats for red drum and Atlantic croaker; 4) determine interspecific dietary overlap between red drum and Atlantic croaker; and 5) determine if red drum and Atlantic croaker feed on equal quantities of food at similar sizes during the co-occurring period.

Materials and Methods

Diurnal sampling (0730 - 1700 h) was conducted weekly from October through December 1994. Fish samples were taken from three stations in Aransas Bay (1H, 2T and 3H) and two stations in Redfish Bay (4H and 5T)(Figure 1). Stations 1H, 3H and 4H were in shoal grass (*Halodule wrightii*) while stations 2T and 5T were in turtle grass (*Thalassia testudinum*) (Figure 1). A 1 m (diameter), 505 µm mesh cone net attached to a 0.75 m (length) x 0.56 m (height)epibenthic sled was hand-towed for 20 m across the grassbed sites. Three samples from each site were obtained, picked free of grass, and preserved in 5% formalin. Standard

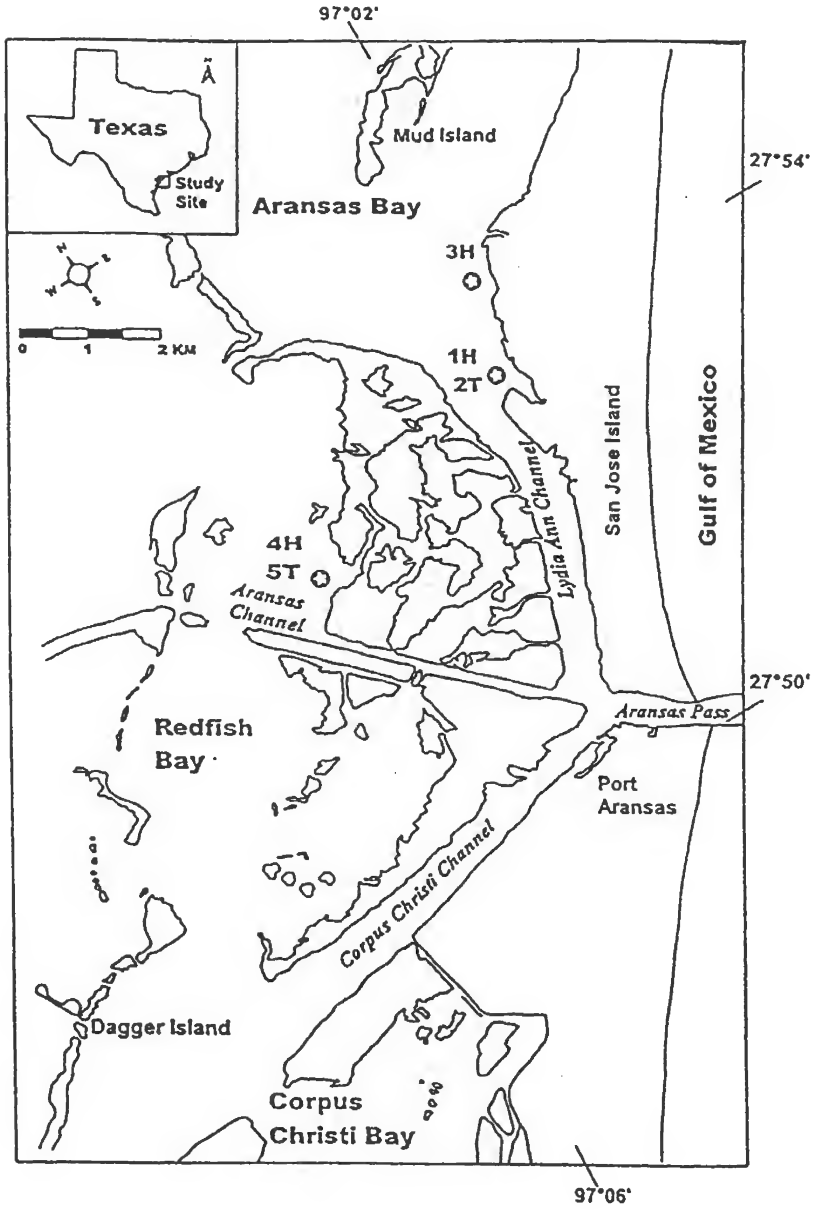

Figure 1. Locations of sampling sites in Aransas Estuary, Texas. Sites were chosen from Shoal grass (*Halodule wrightii* = H) and Turtle grass (*Thalassia testudinum* = T) in Aransas Bay (1H, 2T, 3H) and Redfish Bay (4H, 5T).

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length (SL) of red drum and Atlantic croaker were measured using an ocular micrometer scope. No adjustments for shrinkage were made.

Stomach contents were sorted, counted and identified to lowest possible taxon. For red drum, the development of the stomach (determined by the formation of the pyloric sphincter) begins at approximately 7 - 8 mm SL (personal observation). Consequently, gut content analysis before stomach formation was performed on the entire alimentary canal, and after formation, gut analysis was limited to the stomach to minimize differential rates of digestion. For Atlantic croaker, development of the stomach had begun in all fish examined (personal observation); therefore, gut analysis was limited to the stomach.

When prey items were relatively intact, volumes were determined by measuring the longest length, width, and depth of individual prey using an ocular micrometer scope. Average volumes of prey categories were then calculated (Wallace 1981). For mysids and amphipods, total lengths (TL) were taken when measurable and converted to volumes by a length to volume relationship generated from mysids and amphipods obtained from Site 1H in November 1995. If mysids and amphipods were heavily digested and total length could not be taken, they were divided into three categories (small, medium, and large). The length to volume relationship was subsequently divided into three categories, and average volumes were calculated and assigned to the digested specimens.

Miscellaneous prey is a general group composed of prey items that could not be identified. Miscellaneous prey volume was estimated from a standard length of fish to total prey volume (TPV) relationship (where total prey volume is the sum of all prey item volumes in an individual fish's stomach). If a fish consumed only miscellaneous prey, then the fish's standard length was used to estimate volume.

Red drum (4.00 - 19.99 mm) and Atlantic croaker (8.00 - 17.99 mm) were divided into 2 mm size classes. Three dietary measures were taken for each size class: percent composition by frequency of occurrence (%F), percent numerical abundance (%N), and percent of total volume (%V), where %F = (number of stomachs containing prey of one taxon divided by total number of stomachs that contained any prey items) x 100; %N = (number of individuals of one prey taxon divided by total number of all prey individuals) x 100; and %V = (volume of one prey taxon divided by total volume of all prey) x 100. These three prey measures were used to calculate the Index of Relative Importance (IRI) (Pinkas et al. 1971). The IRI is defined as:

$$IRI = (\%V + \%N)(\%F).$$

This index emphasizes small, numerous prey and de-emphasizes large, less frequently occurring prey and allows for prey items to be ranked quantitatively (Wallace 1981). Empty stomachs were noted and excluded from the above analysis.

Hierarchical cluster analysis was performed to determine ontogenetic trophic patterns across size classes of both red drum and Atlantic croaker (Hartigan 1975). Clustering was based on % IRI values of all prey items from each size class (Table 1 and 2). To determine if rare prey items biased our cluster results, a cluster using the three most important prey items was generated for both red drum and Atlantic croaker. This method produced similar results and, therefore, was excluded from the analysis. Single linkage method (nearest neighbor) was used, and the dissimilarity measure was Euclidean distance. Groupings were determined by cutting the dendrogram at the widest range of Euclidean distance for which the number of clusters remained constant (Romesburg 1984). SYSTAT was used for cluster analysis (Wilkinson 1990).

Schoener's index (1970) is most reliable for measuring dietary overlap when estimates of prey abundance are not available (Wallace 1981, Linton et al. 1981).
Schoener's index is defined as:

$$\alpha = 100\,[1 - 0.5 \sum_{i=1}^{n} | p_{xi} - p_{yi} |],$$

where p_{xi} = proportion (percent IRI) of food category i in the diet of species x; p_{yi} = proportion (percent IRI) of food category i in the diet of species y; n = the number of food categories.

For within-species and between-species overlap comparisons, % IRI values were calculated for prey items from similar-sized fish between stations. Schoener's index was then used to calculate intraspecific and interspecific dietary overlap between stations. When measuring between-species dietary overlap by size-class, red drum and Atlantic croaker from the same size-classes were compared. For this analysis we pooled fish obtained from all habitat types over the three sampling dates when the two fish species co-occurred. For the purposes of discussion, overlap values were classified as: low $\leq$ 33.3%, moderate, 33.3 - 66.6%, and high $\geq$ 66.7%.

Analysis of covariance (ANCOVA) was used to examine the effect of site and habitat on total prey volume (where total prey volume is the sum of all prey item volumes in an individual fish's stomach). ANCOVAs were also used to compare total prey volumes of red drum and Atlantic croaker when the two species co-occured. To reduce "time of day" effect on feeding, only samples from approximately equal times were examined; for example, afternoon samples

TABLE 1

Prey items arranged in descending order of importance by size class (mm SL) of 274 red drum. % IRI = [(% Number + % Volume)(% Frequency)] (100). F = number of fish with food, and E = number of fish with empty guts.

Size Class	I				II				III				IV			
Range (mm SL)	4.00- 5.99				6.00- 7.99				8.00- 9.99				10.00- 11.99			
	F = 14 E = 4				F = 22 E = 5				F = 30 E = 6				F = 39 E = 0			
Prey Categories	%F	%N	%V	%IRI	%F	%N	%V	%IRI	%F	%N	%V	%IRI	%F	%N	%V	%IRI
Mysid shrimp													28.2	6.9	61.4	26.9
Calanoid copepod	14.3	6.9	18.3	7.1	59.1	59.4	45.0	80.4	70.0	69.5	65.1	85.9	48.7	37.3	7.4	30.5
Harpacticoid copepod	21.4	10.3	11.8	9.4	36.4	17.7	5.8	11.1	60.0	13.4	5.4	10.2	71.8	30.9	2.6	33.6
Copepodite species	35.7	44.8	11.5	39.8	13.6	11.5	0.8	2.2	10.0	3.1	0.3	0.3	20.5	5.1	0.1	1.5
Miscellaneous prey	35.7	17.2	23.0	28.5	9.1	2.1	1.7	0.4	3.3	0.3	1.7	0.1	5.1	0.9	1.7	0.2
Copepod species	14.3	17.2	34.6	14.6	22.7	6.3	4.2	3.1	10.0	1.4	1.0	0.2	2.6	0.5	0.1	0.0
Crustacean remains					4.5	1.0	42.4	2.6	0.0	0.0	17.1	0.0	10.3	1.8	19.4	3.0
Amphipod													5.1	0.9	4.6	0.4
Harpacticoid copepodite	7.1	3.4	0.8	0.6	4.5	1.0	0.1	0.1	6.7	0.7	0.1	0.0	17.9	6.0	0.1	1.5
Copepod egg sac					4.5	1.0	0.2	0.1	20.0	3.1	0.6	0.7	23.1	5.5	0.2	1.9
Calanoid copepodite									26.7	7.5	0.8	2.0	7.7	1.8	0.0	0.2
Palaemonetes									6.7	0.7	8.1	0.5	5.1	0.9	2.3	0.2
Cyclopoid copepod													5.1	0.9	0.0	0.1
Penaeus																
Mysid larvae																
Leptochelia																
Hippolydid													2.6	0.5	0.0	0.0
Polychaete																
Copepod nauplius																
Erichsonela																
Total		100.0	100.0	100.0		100.0	100.0	100.0		99.7	100.0	100.0		100.0	100.0	100.0

TABLE 1 (Continued)

Size Class	V				VI				VII				VIII				
Range (mm SL)	12.00- 13.99				14.00- 15.99				16.00- 17.99				18.00- 19.99				
	F = 57 E = 5				F = 36 E = 3				F = 31 E = 0				F = 22 E = 0				
Prey Categories	%F	%N	%V	%IRI	%F	%N	%V	%IRI	%F	%N	%V	%IRI	%F	%N	%V	%IRI	Sum of %IRI
Mysid shrimp	47.4	12.4	63.0	40.8	69.4	23.0	87.8	69.1	80.6	25.1	77.0	69.8	86.4	20.6	81.2	74.8	281.4
Calanoid copepod	47.4	29.7	3.8	18.2	38.9	19.1	1.4	7.2	48.4	30.6	2.1	13.4	36.4	44.6	3.3	14.8	257.5
Harpacticoid copepod	73.7	37.4	2.0	33.2	61.1	38.2	1.2	21.6	58.1	23.5	0.7	11.9	31.8	28.4	0.9	7.9	139.0
Copepodite species	8.8	2.4	0.0	0.2	5.6	1.1	0.0	0.1	6.5	3.3	0.0	0.2					44.2
Miscellaneous prey	1.8	0.3	0.6	0.0	2.8	0.6	0.9	0.0	6.5	1.1	3.3	0.2	4.5	0.5	2.3	0.1	29.6
Copepod species	7.0	5.3	0.5	0.5	2.8	0.6	0.0	0.0	6.5	3.3	0.2	0.2					18.6
Crustacean remains	19.3	3.2	22.0	5.6	5.6	1.1	4.5	0.3	6.5	1.1	2.0	0.2	18.2	2.0	7.7	1.5	13.1
Amphipod	7.0	1.5	7.4	0.7	5.6	1.7	2.8	0.2	25.8	6.0	9.8	3.4	13.6	2.0	3.7	0.7	5.4
Harpacticoid copepodite	14.0	3.5	0.0	0.6	11.1	7.9	0.1	0.8									3.6
Copepod egg sac	7.0	2.4	0.1	0.2	13.9	4.5	0.1	0.6	3.2	0.5	0.0	0.0	4.5	0.5	0.0	0.0	3.4
Calanoid copepodite	3.5	0.6	0.0	0.0					3.2	0.5	0.0	0.0	4.5	0.5	0.0	0.0	2.3
Palaemonetes	1.8	0.3	0.5	0.0	5.6	1.1	1.1	0.1	12.9	2.7	2.4	0.6	9.1	1.0	0.9	0.1	1.6
Cyclopoid copepod	3.5	0.6	0.0	0.0	2.8	0.6	0.0	0.0									0.1
Penaeus									3.2	0.5	2.2	0.1					0.1
Mysid larvae	1.8	0.3	0.0	0.0					3.2	0.5	0.0	0.0					0.0
Leptochelia									3.2	0.5	0.2	0.0					0.0
Hippolydid																	0.0
Polychaete									3.2	0.5	0.0	0.0					0.0
Copepod nauplius					2.8	0.6	0.0	0.0									0.0
Erichsonela	1.8	0.3	0.1	0.0													0.0
Total		100.0	100.0	100.0		100.0	100.0	100.0		100.0	100.0	100.0		100.0	100.0	100.0	

TABLE 2

Prey items arranged in descending order of importance by size class (mm SL) of 205 Atlantic croaker. % IRI = [(% Number + % Volume)(% Frequency)] (100). F = number of fish with food, and E = number of fish with empty guts.

Size Class	I				II				III			
Range (mm SL)	8.00- 9.99				10.00- 11.99				12.00- 13.99			
	F = 6	E = 18			F = 37	E = 14			F = 56	E = 9		
Prey Categories	%F	%N	%V	%IRI	%F	%N	%V	%IRI	%F	%N	%V	%IRI
Harpacticoid copepod	16.7	5.0	3.1	1.5	64.9	26.9	5.9	23.9	69.6	38.6	3.5	34.3
Calanoid copepod	50.0	75.0	94.0	94.2	70.3	48.7	21.5	55.5	30.4	22.8	4.2	9.6
Mysid shrimp					24.3	5.1	59.8	17.7	46.4	12.6	81.1	50.9
Harpacticoid copepodite	16.7	5.0	0.5	1.0	18.9	4.1	0.1	0.9	21.4	8.9	0.1	2.3
Copepodite species	16.7	5.0	0.8	1.1	13.5	4.1	0.2	0.7	19.6	8.9	0.2	2.1
Crustacean remains					5.4	1.0	6.1	0.4				
Calanoid copepodite	16.7	10.0	1.6	2.2	8.1	2.5	0.1	0.2	1.8	0.4	0.0	0.0
Copepod egg sac					5.4	1.0	0.1	0.1	5.4	1.2	0.0	0.1
Palaemonetes species					2.7	0.5	2.6	0.1	5.4	1.2	2.6	0.2
Bivalve												
Copepod species					5.4	4.1	1.5	0.3	1.8	1.2	0.2	0.0
Sagitta species									5.4	1.2	4.6	0.4
Cyclopoid copepod									1.8	0.4	0.8	0.0
Miscellaneous prey									1.8	0.4	1.2	0.0
Amphipod									3.6	0.8	1.0	0.1
Isopod					2.7	0.5	1.1	0.1				
Polychaete									1.8	0.4	0.0	0.0
Alpheus species					2.7	0.5	0.9	0.0				
Copepod nauplius					2.7	1.0	0.0	0.0	1.8	0.4	0.0	0.0
Leptochelia rapax									1.8	0.4	0.4	0.0
Total		100.0	100.0	100.0		100.0	100.0	100.0		100.0	100.0	100.0

TABLE 2 (Continued)

Size Class	IV				V				
Range (mm SL)	14.00- 15.99				16.00- 17.99				
	F = 34	E = 14			F = 13	E = 4			
Prey Categories	%F	%N	%V	%IRI	%F	%N	%V	%IRI	Sum of %IRI
Harpacticoid copepod	70.6	43.0	3.0	42.0	76.0	52.0	7.0	70.0	172.0
Calanoid copepod	5.9	1.0	0.0	0.0					159.0
Mysid shrimp	35.3	12.0	76.0	40.0	7.0	2.0	69.0	8.0	117.0
Harpacticoid copepodite	47.1	21.0	0.0	13.0	30.0	11.0	0.0	5.0	23.0
Copepodite species	8.8	2.0	0.0	0.0	23.0	23.0	0.0	8.0	12.0
Crustacean remains	5.9	2.0	6.0	0.0	15.0	5.0	21.0	6.0	7.0
Calanoid copepodite									2.0
Copepod egg sac	20.6	6.0	0.0	1.0					2.0
Palaemonetes species	5.9	1.0	3.0	0.0					0.0
Bivalve					7.0	2.0	0.0	0.0	0.0
Copepod species	2.9	1.0	0.0	0.0					0.0
Sagitta species									0.0
Cyclopoid copepod	2.9	1.0	3.0	0.0					0.0
Miscellaneous prey	2.9	0.0	3.0	0.0					0.0
Amphipod	2.9	0.0	1.0	0.0					0.0
Isopod									0.0
Polychaete	2.9	0.0	0.0	0.0					0.0
Alpheus species									0.0
Copepod nauplius									0.0
Leptochelia rapax									0.0
Total		100.0	100.0	100.0		100.0	99.0	100.0	

were compared only to afternoon samples. Standard Length was the covariate in all analyses. ANCOVAs were performed when more than 15 fish were present in the sample. Total prey volumes were square-root transformed to approximate a normal distribution and to minimize heteroscedasticity. Analysis of covariance is robust to departures from both normality and homogeniety of variances; therefore, minor deviations from assumptions should not affect results (Underwood 1981). An interactive regression model (SYSTAT 1990) was performed prior to ANCOVA to confirm the homogeneity of slopes assumption. If the homogeneity of slopes assumption was violated, then the interactive regression model results were reported. When making multiple statistical comparisons, alpha levels were adjusted using the sequential Bonferroni test (Rice 1989).

RESULTS

The relationship between total length to volume for mysid shrimp was: $V = 0.02L^{2.89}$ ($R^2 = 0.99$), whereas the relationship between total length to volume for amphipods was: $V = 0.02L^{3.30}$ ($R^2 = 0.97$). These relationships were used to estimate mysid shrimp and amphipod volumes from total length estimates made for mysids and amphipods obtained from gut contents of red drum and Atlantic croaker.

A total of 274 red drum between 4.00 - 19.99 mm SL, and 205 Atlantic croaker between 8.00 - 17.99 mm SL were examined for gut content (Tables 1 and 2). Of the red drum examined, 8.4% had empty guts, while 28.8% of Atlantic croaker guts contained no food. The highest percentage of empty stomachs for red drum occurred in the smallest size class (22.2%). Three size classes of red drum had no fish with empty stomachs (10.00 - 11.99, 16.00 - 17.99, and 18.00 - 19.99). Atlantic croaker from the smallest size-class (8.00 - 9.99) had the greatest proportion of empty stomachs (75 %), while fish from size class (12.00 - 13.99) had the least proportion (13.8%).

Red Drum

Percent Composition of Diet

Twenty taxonomic groups were identified from the guts of red drum (Table 1). Calanoid copepods and harpacticoid copepods were the most numerous prey consumed by fish from all size classes. Mysid shrimp were consumed by the five largest size classes (10.00 - 19.99) and comprised most of the dietary volume in those size classes. Harpacticoid copepodites, copepod egg sacs, and calanoid copepodites occurred in moderate numbers in some size classes (8.00 - 9.99, 10.00 - 11.99), but comprised only a small fraction of the total volume. In the 16.00 - 17.99 mm size class, amphipods comprised 25.81 by % Frequency, 6.01 by % Number, and 9.76 by % Volume, and were the fourth most important prey for that size class.

Relative Importance of Prey

Mysid shrimp, calanoid copepods, and harpacticoid copepods were the three major prey items consumed by red drum and together averaged 84.7% IRI across all size classes (Table 1). Red drum showed ontogenetic shifts in feeding (Figure 2). Calanoid copepods were ingested by red drum in all size classes but were dominant prey for smaller red drum (6.00 - 9.99 mm). Harpacticoid copepods were also ingested by red drum from all size classes and were especially important to fish in the intermediate size classes (10.00 - 15.99 mm). Mysid shrimp were first consumed by fish in the 10.00 - 11.99 mm size class and became the most important prey item thereafter. Prey items from the smallest size class were heavily digested and difficult to identify,

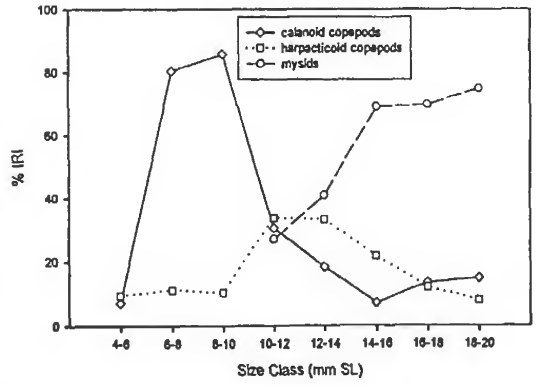

Figure 2. Relative importance values (IRI) by size class (mm SL) of the three major prey items for red drum (*Sciaenops ocellatus*).

and as a result, the general groups copepodites and miscellaneous prey accounted for 39.78 and 28. 45% IRI, respectively. Sixteen of the twenty taxonomic groups found in red drum also occurred in Atlantic croaker. *Penaeus* sp., mysid larvae, Hippolydids, and *Erichsonela* sp. were unique to the diet of red drum, but were of little importance (%IRI = < 1 for each).

Atlantic Croaker

Percent Composition of Diet

Twenty taxonomic groups were identified from Atlantic croaker stomachs (Table 2). Harpacticoid copepods and

calanoid copepods were the most numerous and most frequent prey items consumed by Atlantic croaker. Mysid shrimp were not numerous in the stomachs of Atlantic croaker; however, this prey item accounted for most of the total volume. While some prey items had relatively high % Frequency and % Number values in some size classes, their small size reduced % IRI values. For example, harpacticoid copepodites in the 14.00 - 15.99 mm size class accounted for 47.1% Frequency and 21.7% Number, but by volume, represented only 0.3%. In the same size class, copepod egg sacs occurred in 20.6% of fish and accounted for 6.6% by number but only comprised 1.8% by volume.

Relative Importance of Prey

Harpacticoid copepods, calanoid copepods and mysid shrimp were the three major prey items identified in Atlantic croaker, together averaging 89.9% IRI across size classes (Table 2). Ontogenetic shifts in diet composition were detected for Atlantic croaker as well (Figure 3). Harpacticoid copepods were ingested by fish in all size classes. Their consumption increased gradually across the size spectrum and were most important to 14.00 to 17.99 mm fish. Calanoid copepods were dominant prey for smaller Atlantic croaker (8.00 - 11.99 mm). Mysid shrimp were first consumed by Atlantic croaker in the 10.00 - 11.99 mm size class and were the major prey for intermediate-sized fish (12.00 - 13.99 mm). Bivalves, *Sagitta* sp., isopods, and *Alpheus* sp. were unique to Atlantic croaker diet but each accounted for less than one percent IRI.

Hierarchical Cluster Analysis

The eight size classes of red drum clustered to form three trophic groups: 4.00 - 5.99 mm, 6.00 - 9.99 mm, and 10.00 - 19.99 mm (Figure 4). The diets of fish in the 4.00 - 5.99 mm size group were dissimilar to diets of fish from all other groups because of heavily digested prey (miscellaneous prey). Fish from the 6.00 - 7.99 mm and 8.00 - 9.99 mm size classes fed primarily on calanoid copepods (%IRI = 80.43, and 85.91, respectively); consequently, the two size classes grouped together. Red drum greater than 10.00 mm formed a separate cluster. Within this group there appeared to be some evidence for further separation. Fish from the intermediate size classes (10.00 - 11.99 mm, 12.00 - 13.99 mm) fed on relatively equal proportions of mysid shrimp, calanoid copepods, and harpacticoid copepods. Red drum from the larger size classes (14.00 - 15.99 mm, 16.00 - 17.99 mm, and 18.00 - 19.99 mm) clustered to form a group which fed primarily on mysid shrimp (%IRI = 69.10, 69.75, and 74.79, respectively).

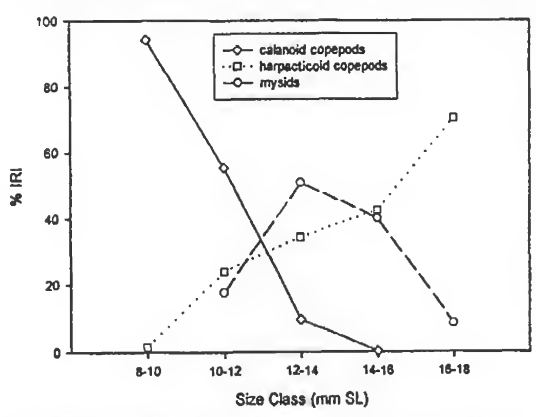

Figure 3. Relative importance values (IRI) by size class (mm SL) of the three major prey items for Atlantic croaker (*Micropogonias undulatus*).

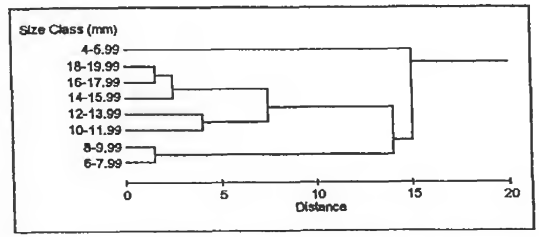

Figure 4. Dendrogram for hierarchical cluster analysis of diet dissimilarity of eight size classes (mm SL) of red drum (*Sciaenops ocellatus*). Clustering was based on% IRI (Index of Relative Importance) of all prey items. Single linkage clustering and Euclidean distance were used.

Four trophic groups were identified for Atlantic croaker (Figure 5). Size classes 8.00 - 9.99 mm, 10.00 - 11.99 mm, and 16.00 - 17.99 mm each had distinct diets (Table 2) and did not cluster with any other size class. The size class, 8.00 - 9.99 mm fed almost exclusively on calanoid copepods (%IRI = 94.2) while the size class, 10.00 - 11.99 mm consumed a combination of mysid shrimp, harpacticoid copepods and calanoid copepods (%IRI = 55.5, 23.9, and 17.7, respectively). Larger Atlantic croaker from size class 16.00 - 17.99 mm ingested mainly harpacticoid copepods (%IRI = 70.4). Intermediate size classes 12.00 - 13.99 mm and 14.00 - 15.99 mm combined to form a group which fed on equal proportions of mysid shrimp and harpacticoid copepods.

Site and Habitat Dietary Comparison

Red drum

Site and habitat did not affect the type or quantity of food ingested by red drum. This species exhibited moderate

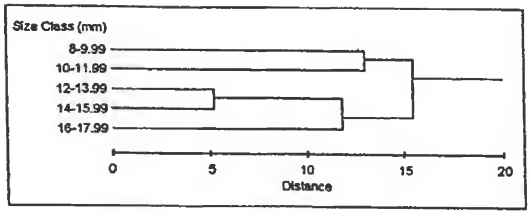

Figure 5. Dendrogram for hierarchical cluster analysis of diet dissimilarity of eight size classes (mm SL) of Atlantic croaker (*Micropogonias undulatus*). Clustering was based on % IRI (Index of Relative Importance) of all prey items. Single linkage clustering and Euclidean distance were used.

intraspecific dietary overlap values between the two seagrass types (Table 3). Moderate and high values were observed between the two *H. wrightii* sites (Table 3).

No significant difference in total prey volume was observed for red drum taken from the two seagrass types (1H versus 2T, Table 4). Moreover, when comparing total prey volume of fish diets taken from the two sites in *H. wrightii* (1H versus 3H), red drum contained similar amounts of food as well (Table 4).

Atlantic croaker

For Atlantic croaker, site and habitat did not affect the type of food but did affect the quantity of food consumed by this species. Atlantic croaker taken from both seagrass types ingested almost identical prey (Schoener = 95%, Table 5). Furthermore, a 73% dietary overlap was observed for Atlantic croaker taken from two sites in *H. wrightii* (1H versus 3H).

Atlantic croaker showed no significant difference in total prey volume between the two seagrass types (Table 6). However, there was a significant difference in total prey volumes between fish from the two sites in *H. wrightii* (1H versus 3H, ANCOVA, p = .004).

Interspecific Dietary Comparison

Interspecific dietary overlap (Schoener's index) was calculated for red drum and Atlantic croaker from five size-classes ranging from 8.00 - 17.99 mm SL (Figure 6). Red drum and Atlantic croaker exhibited high overlap values in excess of 70 % in four of the five size classes. However, low dietary overlap (23 %) was observed in the largest size class (16.00 - 17.99 mm SL). Interspecific dietary overlap values were consistently high when red drum and Atlantic croaker from identical samples were compared (Table 7). Four of the five comparisons encompassing three sampling dates (7 November, 16 November and 21 November) and four times (0830 h, 0946 h, 1445 h and 1630 h) had overlap values in excess of 76%. Moderate overlap values (Schoener = 39%) were observed at Site 1H (7 November)(Table 7).

Total prey volumes were significantly higher for red drum than for Atlantic croaker at Site 1H and Site 3H on 7 November and 16 November, respectively (Table 8). At Site 3H (16 November) red drum and Atlantic croaker contained similar amounts of food, but were affected differently with respect to Standard Length (slopes intersected, interactive regression, P = .000).

TABLE 3

Estimated dietary overlap (Schoener's index) for red drum between sites. N is sample size, and SL is standard length.

Date (1994) Site	Size	Range (mm SL)	N	% Dietary Overlap
7-Nov	1H	8.0 - 14.1	48	66.0
	2T	8.8 - 15.2	24	
7-Nov	1H	8.0 - 14.1	48	43.8
	3H	8.1 - 13.5	27	
7-Nov	2T	8.8 - 15.2	24	45.2
	3H	8.1 - 13.5	27	
16-Nov	1H	10.5 - 13.4	9	71.7
	3H	9.5 - 13.9	18	

TABLE 4

ANCOVA comparison of Total Prey Volume (TPV) of red drum between sites. N is sample size, SE is Standard Error of the mean, and P is the probability of Type I Statistical error.

Date (1994)	Site	Time	N	SL Mean (mm)	SE	Volume Mean (mm3)	SE	P-value
	1H	1430 h	65	12.6	0.3	1.46	0.1	
7-Nov								0.414
	2T	1530 h	28	13.1	0.5	1.37	0.2	
	1H	1430 h	65	12.6	0.3	1.46	0.1	
7-Nov								0.156
	3H	1630 h	33	11.5	0.5	0.97	0.2	
	2T	1530 h	28	11.5	0.5	0.97	0.1	
7-Nov								0.473
	3H	1630 h	33	13.1	0.5	1.37	0.2	
	1H	830 h	16	13.8	0.5	1.85	0.3	
16-Nov								0.514
	3H	946 h	23	13	0.5	1.39	0.3	

TABLE 5

Estimated dietary overlap for Atlantic croaker between sites. N is sample size, and SL is standard length.

Date (1994)	Site	Size Range (mm SL)	N	% Dietary Overlap
	1H	10.1 - 14.2	37	
16-Nov				73.2
	3H	10.7 - 16.0	27	
	1H	12.0 - 17.29	17	
21-Nov				95.0
	2T	12.0 - 17.8	55	

TABLE 6

ANCOVA comparison of Total Prey Volume (TPV) of Atlantic croaker between sites. N is sample size, SE is Standard Error of the mean, and P is the probability of Type I statistical error.

Date (1994)	Site	Time	N	SL Mean	SE	Volume Mean (mm3)	SE	P-value
	1H	830 h	37	12.3	0.2	0.82	0.09	
16-Nov								.004[$]
	3H	946 h	27	13.8	0.2	1.38	0.12	
	1H	1445 h	17	15.2	0.4	0.14	0.1	
21-Nov								0.14
	2T	1345 h	57	14.7	0.2	0.31	0.06	

[$] Significant after alpha adjustment (Rice 1989).

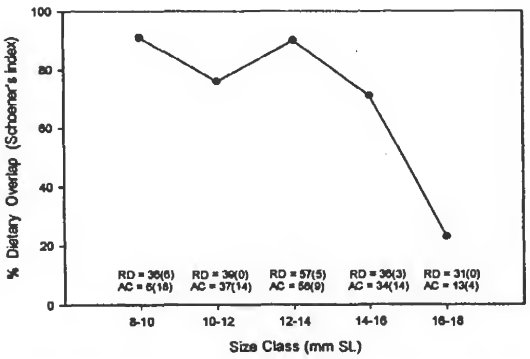

Figure 6. Fish size class (mm SL) versus interspecific dietary overlap (Schoener's index). Parentheses indicate number of fish with empty guts.

DISCUSSION

The proportion of empty stomachs found in red drum (8.4%) was less than that reported in other studies. All fish examined in the present study were obtained from seagrass beds and sampled diurnally. Bass and Avault (1975) reported 11.7% of red drum less than 19 mm SL had empty guts while 17% of red drum (8.00 - 15.00 mm SL) examined by Peters and McMichael (1987) contained no food. Those studies pooled day and night collected fish and did not specify whether the fish used were pelagic or demersal. Both variables have been shown to affect food consumption of larval and juvenile fish (Govoni et al. 1983, Kane 1984). Atlantic croaker from the smallest size class had the highest percentage of empty stomachs (75%). High percentages of empty stomachs (49%) have been reported by Govoni et al. (1983) for pelagic Atlantic croaker (5.01 - 10.00 mm SL). The higher percentage of empty stomachs in Atlantic croaker compared to red drum may be due to these fish feeding in the evening or at night, or to seagrass beds not being primary nursery habitat for Atlantic croaker. Larval and juvenile fish probably do not feed at night (Blaxter 1986). While it has been shown that larval and juvenile red drum prefer seagrass beds as nursery habitat (Rooker and Holt 1997, Holt et al. 1983), seagrass may not be primary habitat for Atlantic croaker since they have been found in high densities at equal sizes in other habitats, such as sand, mud and deeper waters (Holt and Arnold 1989, Chao and Musick 1977).

Of the 20 prey items ingested by larval and juvenile red drum and Atlantic croaker, 16 were common to both species. The same three prey, calanoid copepods, harpacticoid copepods, and mysid shrimp, dominated the diet of both species. Other studies examining demersally caught red drum showed similar patterns (Bass and Avault 1975, Peters and McMichael 1987). These investigations found copepods (calanoids, harpacticoids, and cyclopoids) to be dominant food items for fish less than 8 - 9 mm SL, while mysid shrimp became the principal prey for red drum greater than 9 - 10 mm SL. Steen and Laroche (1983), examining 21 demersally caught red drum between 8.50 - 12.99 mm SL, observed a different pattern. They found decapod postlarvae and a calanoid copepodite to be most important. Sheridan (1979) found insect larvae and

TABLE 7

Estimated dietary overlap (Schoener's index) between red drum and Atlantic croaker by site. N is sample size, and SL is standard length.

Date (1994)	Site	Time	Species	N	Size Range (mm SL)	% Dietary Overlap
7-Nov	1H	1430 h	Atlantic croaker	8	9.2 - 13.2	38.9
			red drum	48	8.0 - 14.1	
7-Nov	3H	1630 h	Atlantic croaker	16	9.3 - 13.4	97.4
			red drum	27	8.1 - 13.5	
16-Nov	1H	830 h	Atlantic croaker	37	10.1 - 14.2	81.3
			red drum	9	10.5 - 13.4	
16-Nov	3H	946 h	Atlantic croaker	27	10.7 - 16.0	85.9
			red drum	23	9.5 - 17.5	
21-Nov	1H	1445 h	Atlantic croaker	17	12.0 - 17.3	76.8
			red drum	7	12.8 - 17.4	

TABLE 8

ANCOVA comparison of Total Prey Volume (TPV) between red drum and Atlantic croaker. N is sample size, SE is standard error of the mean, and P is the probability of Type I statistical error.

Date (1994)	Time	Species	N	SL Mean	SE	Volume Mean (mm^3)	SE	P-value
		Red drum	33	11.5	0.4	0.97	0.1	
7-Nov	1630 h							0[s]
		Atlantic croaker	16	11.1	0.7	0.33	0.14	
		Red drum	16	13.8	0.4	1.85	0.18	
16-Nov	830 h							0.001[s]
		Atlantic croaker	37	12.3	0.3	0.82	0.12	
		Red drum	23	12.99	0.34	1.39	0.19	
16-Nov	946 h							.0000*[s]
		Atlantic croaker	27	13.75	0.38	1.38	0.17	

* Interactive regression results (slopes intersected).

[s] Significant after alpha adjustment (Rice 1989).

polychaetes to be primary prey for Atlantic croaker (10 - 19 mm SL) although calanoid copepods, harpacticoid copepods, and mysid shrimp were also reported.

Prey assemblages differ in a pelagic compared to a demersal environment (Rudnick et al. 1985). Steen and Laroche (1983) described a different trophic pattern for pelagic red drum. They found copepod eggs and a cyclopoid copepodite (*Oithona* sp.) to be most important to fish between 3.00 - 8.49 mm SL. Govoni et al. (1983), examining food of pelagic Atlantic croaker up to 10 mm SL, showed a slightly different pattern as well. Calanoid copepods, copepod fragments, and invertebrate eggs were major prey identified in that study.

Pelagic red drum and Atlantic croaker arrive in seagrass beds at approximately 4 - 5 mm SL and 8 - 9 mm SL, respectively. Consequently, the major prey of both fish at the smaller size classes are calanoid copepods, a more pelagic group of copepods. Conversely, harpacticoid copepods are found in higher concentrations in seagrass beds than in a pelagic environment (Stoner 1980, Orth et al. 1984), and become important prey for intermediate-sized red drum and larger Atlantic croaker. The ontogenetic shift from calanoid copepods to harpacticoid copepods is probably due to a higher abundance of this prey in the seagrass habitat and not to morphological constraints in feeding since harpacticoids in general are smaller than calanoid copepods. Thus, the shift from calanoid copepods to harpacticoid copepods indicates the transition from a pelagic environment to settlement into grassbeds. Steen and Laroche (1983) described a similar settlement pattern for red drum and Sheridan (1979) for Atlantic croaker, occurring at similar sizes.

Red drum can be divided into two distinct trophic niche stages with a transition occurring at the 10.00 - 11.99 mm size class. Red drum, <9.99 mm SL, feed almost exclusively on calanoid copepods, while fish ≥12.00 mm consume primarily mysid shrimp. The transition (10.00 - 11.99 mm) is characterized by the ingestion of relatively equal proportions of calanoid copepods, harpacticoid copepods, and mysid shrimp. Discrete trophic niche stages were also detected for Atlantic croaker. Fish from the 10.00 - 13.99 mm size range marked a transition. Atlantic croaker from this size range showed the greatest diet change. Harpacticoid copepod and mysid shrimp consumption increased while calanoid copepod ingestion decreased. Atlantic croaker <9.99 mm SL, ingested almost entirely calanoid copepods while fish ≥14.00 mm ingested primarily harpacticoid copepods and mysid shrimp. Based on ontogenetic trophic niche shifts, red drum and Atlantic croaker can be divided into ecologically distinct stages that could serve to minimize intraspecific competition for food (Olson 1996).

Site and habitat did not affect the types or quantity of food ingested by red drum. These results support findings by Rooker et al. (1997) that nutritional condition of larval and juvenile red drum did not differ between seagrass type (*H. wrightii* vs. *T. testudinum*) or between various *H. wrightii* sites. Consequently, larval and juvenile red drum appear to be in good nutritional condition in seagrass beds.

Atlantic croaker ingested the same types of prey items regardless of site and habitat which may imply that either prey assemblages are similar at the three sites, or that red drum and Atlantic croaker select the same prey from each of the sites. Atlantic croaker taken from site 3H ingested greater quantities of food compared to other Atlantic croaker at other sites (Table 6), and relatively equal quantities compared to red drum (Table 8). This may indicate spatial variation in prey abundance in seagrass meadows (Orth 1984) or that this particular site (3H) is more suitable habitat for Atlantic croaker. Interestingly,

larval and juvenile red drum were shown to have increased growth rates at this particular site (Rooker et al. 1997).

Although previous investigations have demonstrated partitioning of prey among species of larval fish (Laroche 1982, Govoni et al. 1983), little evidence of this was observed for red drum and Atlantic croaker in the present study. High dietary overlap (Schoener's index) was observed throughout most of the size range and at most stations, although a decrease in dietary overlap (23%) was observed at the largest size class (16.0 - 17.9 mm SL). Sheridan (1979) found diets of Atlantic croaker (10 - 59 mm SL) and Spot (*Leiostomus xanthurus*) (20 - 79 mm SL) to be similar.

High dietary overlap values in the present study must be interpreted with caution since identifying prey to lower taxonomic levels could have reduced dietary overlap values given that these fish are able to select for different prey at the lower taxonomic levels (Motta et al. 1995). For example, if one species of fish selected for a particular species of calanoid copepod, then dietary overlap values would almost certainly decrease.

Red drum and Atlantic croaker may also partition resources by feeding at different times of the day. For example, one species may feed nocturnally and the other diurnally. Studies have shown that larval and juvenile fishes at these stages lack appropriate number of neuromast and retinal rod cells (O'Connell 1981, Poling and Fuiman in press); therefore, efficient nocturnal foraging is probably not likely. In addition, diel food habits studies have shown gut fullness declines considerably at night (Kjelson 1975, Archambault and Feller 1991). Furthermore, most fish caught nocturnally have higher proportions of empty guts than fish caught diurnally (Govoni et al. 1983). Resources can also be partitioned by one species foraging more intensely at a different time of the day than the other. Since high dietary overlap was observed throughout the entire day, resource partitioning of this type is probably not likely.

In order for competition for food to occur, prey must be limiting, there must be high dietary overlap, and there has to be a negative effect on one or more species (Schreck and Moyle 1990). No data on prey abundance was taken; therefore, arguments for a limiting resource are difficult to make. Evidence for the latter two requirements is provided. Three cases for high dietary overlap are: 1) the same three prey types were most important to both species; 2) high dietary overlap (Schoener's index) was observed between Atlantic croaker and red drum throughout most of the size range and at most stations; and 3) both species showed similar ontogenetic trophic niche stages during the co-occurring period. Evidence of a negative effect on Atlantic croaker feeding is: 1) there was a greater proportion of empty stomachs found in Atlantic croaker (28.8%) compared to red drum (8.4%); 2) Atlantic croaker are able to ingest as much prey as red drum but did not at times; and 3) there was an absence of mysid shrimp in Atlantic croaker stomachs at the largest size range. Of the three major prey items, mysid shrimp are the largest by volume and probably constitute the greatest caloric gain. Laboratory experiments to support the negative affect on Atlantic croaker feeding should be conducted.

Chao and Musick (1977) have suggested that sciaenid fishes separate use of nursery habitat to potentially reduce interspecific competition for food. Similarly, Rooker et al. (1998) showed that newly settled red drum (4.0 - 30 mm SL) and Atlantic croaker (8.0 - 20 mm SL) stagger occupancy of seagrass beds. The overlap period when similar-sized larval and juvenile red drum and Atlantic croaker co-occur lasts for only a few weeks (Rooker et al. 1998). Thus, red drum and Atlantic croaker may temporarily separate use of seagrass beds to partition food resources. Moreover, these two species may have evolved to spawn at different times of the year or at different distances from nursery habitat to reduce competition for food.

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An Illustrated Record and Range Extension of *Caligus chelifer* (Copepoda, Siphonostomatoida) in the Gulf of Mexico

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AN ILLUSTRATED RECORD AND RANGE EXTENSION OF *CALIGUS CHELIFER* (COPEPODA, SIPHONOSTOMATOIDA) IN THE GULF OF MEXICO

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ABSTRACT A male specimen of the copepod *Caligus chelifer* Wilson, 1905, was collected during a plankton survey carried out during February 1994 off the Mexican coasts of the eastern Gulf of Mexico (Tamaulipas state). This is the first record of this species in Mexican waters and south of the 25°N in the Northwestern Atlantic. Taxonomic illustrations of the specimen are provided.

Introduction

The genus *Caligus* comprises about 200 species and is one of the most widely distributed groups of parasitic copepods in the world seas. They parasitize teleosts, such as mackerels and tuna, and several species of elasmobranchs (Kabata, 1979; Cressey and Cressey 1980).

In the Gulf of Mexico and western Caribbean Sea, 26 species of *Caligus* have been recognized (Cressey 1991). Most of these specimens have been collected directly from the host; however, it is not uncommon to find caligids and their close allies captured by plankton nets as they are relatively loosely attached to their host surfaces (Kabata 1979).

From a plankton survey carried out at the central-westernmost portion of the Gulf of Mexico, a single male of a *Caligus* species previously unreported in Mexican waters was collected. Although the host fish remains unknown, we present the record along with taxonomic illustrations of the specimen.

Material and Methods

Zooplankton from 47 stations were collected from 16-21 February, 1994, during the oceanographic cruise EMOAPII (Estudio de las Modificaciones Oceanográficas y Ambientales Producidas por la Influencia del Río Pánuco), carried out by the Estación de Investigación Oceanográfica de Tampico, on board the oceanographic vessel "Antares". Samples were taken between the southern portion of the Tamaulipas state coastline and the northern coast of Veracruz state, off the Laguna de Tamiahua (21°45'0.72" and 22°49'18" N; 97°2'15'0.72" and 97°48'4.32" W). The specimen of *Caligus* was sorted from a sample collected at station 10 (22° 23.43'N; 97° 41.00'), on February 18 at 06:52 h. It was then processed for identification. All the taxonomically relevant structures were illustrated. The specimen is deposited in Dr. Kim's collection at the Kangreung National University, South Korea.

Results and Discussion

The taxonomic analysis of the specimen resulted in the identification of a male *Caligus chelifer* Wilson 1905, which was illustrated showing the main taxonomic features of the genus (Figures 1 and 2). The male of this species can be readily distinguished from the other species of *Caligus* by the slender, tapering urosome (Figure 1) and the presence, on the corpus of the maxilliped, of a strong protrusion which gives the appendage a chelate appearance when the claw is set in resting position (Wilson 1905; Kabata 1972; Cressey and Cressey 1980) (see Figure 1H).

The specimen had a total length of 4.15 mm, and the cephalothorax is 2.38 mm long and 1.63 mm wide. Genital complex measured 0.74 mm long and 0.53 mm wide. Our specimen seems to be a small one when comparing it with the measurements reported by Wilson (1905) for the type specimen (total length: 4.93 mm, cephalothorax length: 3 mm, width: 2.1mm, genital complex: 1.0 mm) and for additional, larger specimens (6-6.5 mm, 3 mm, 2.3 mm, 1.6 mm, respectively) (Wilson 1905; Cressey 1991).

Caligus chelifer has a 2-segmented exopod of leg 4 (Figure 2E); its first segment bears a spine on outer distal corner; the distal segment has a spine on midlength of outer margin, plus 3 large terminal spines. Of all the species recorded for the Gulf of Mexico and the Caribbean Sea (Wilson 1936; Yamaguti 1963; Cressey 1991), half of them show this leg 4 segmentation and armament (*C. afurcatus* Wilson 1913; *C. asperimanus* Pearse 1951; *C. berychis* Wilson 1936; *C. bonito* Wilson 1905; *C. epinephali* Yamaguti 1936; *C. haemulonis* Krøyer 1863; *C. mutabilis* Wilson 1905; *C. ocyurus* Cressey 1991; *C. praetextus* Bere 1936; *C. productus* Dana 1852; *C. rufimaculatus* Wilson 1905; *C. suffuscus* Wilson 1913; *C. xystercus* Cressey 1991). Only three of these (*C. mutabilis, C. ocyurus* and *C. praetextus*) have the genital complex and caudal rami longer than wide, as in *C. chelifer*. Particularly, *C. chelifer* resembles *C. praetextus* as both

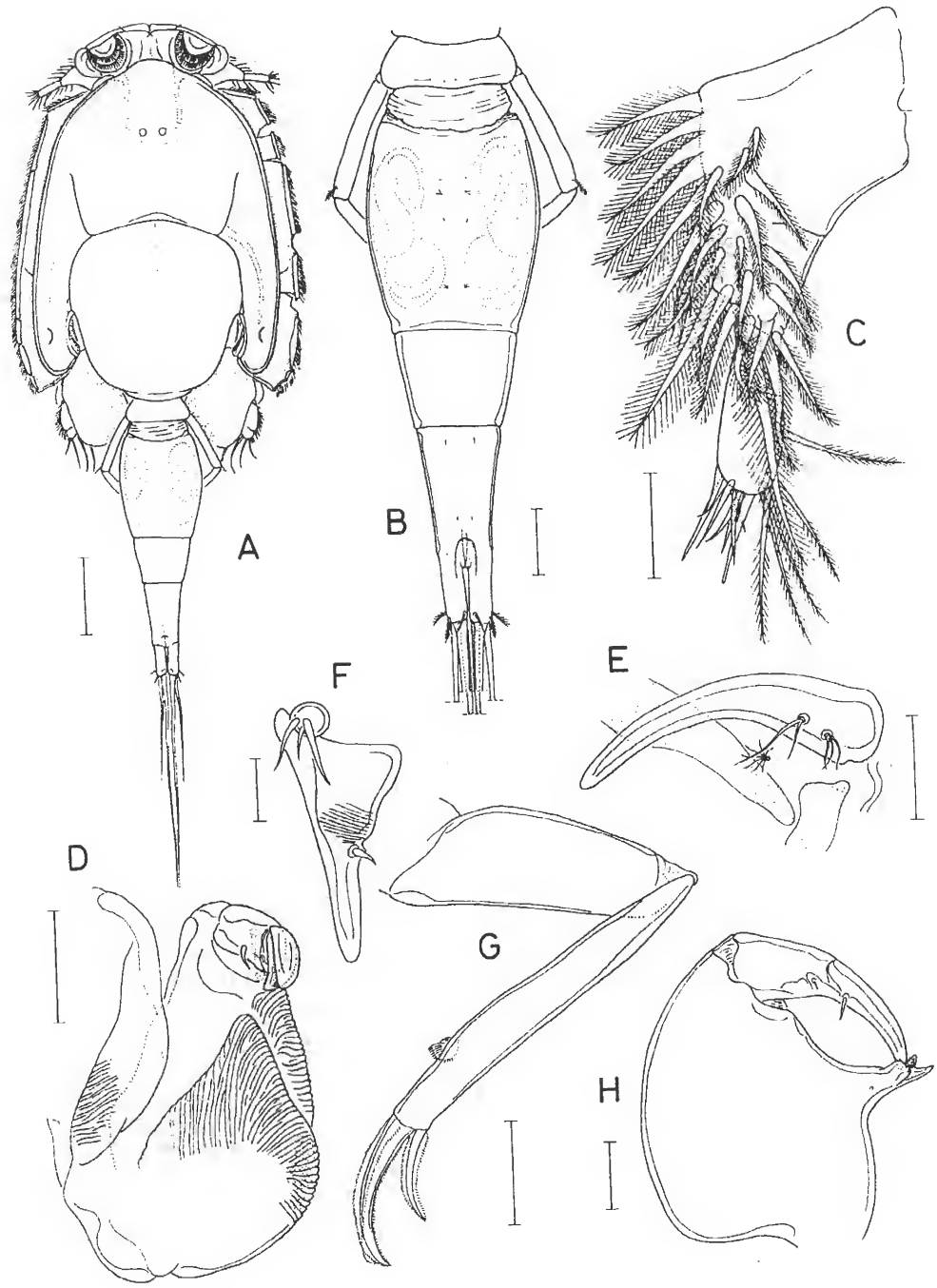

Figure 1. ***Caligus chelifer*****, adult male: A. Habitus, dorsal; B. urosome, dorsal; C. antennule; D. antenna; E. postantennary process; F. maxillule; G. maxilla; H. maxilliped. Scales: A= 0.5mm; B= 0.2mm; C-E,G,H= 0.1 mm; F=0.05 mm.**

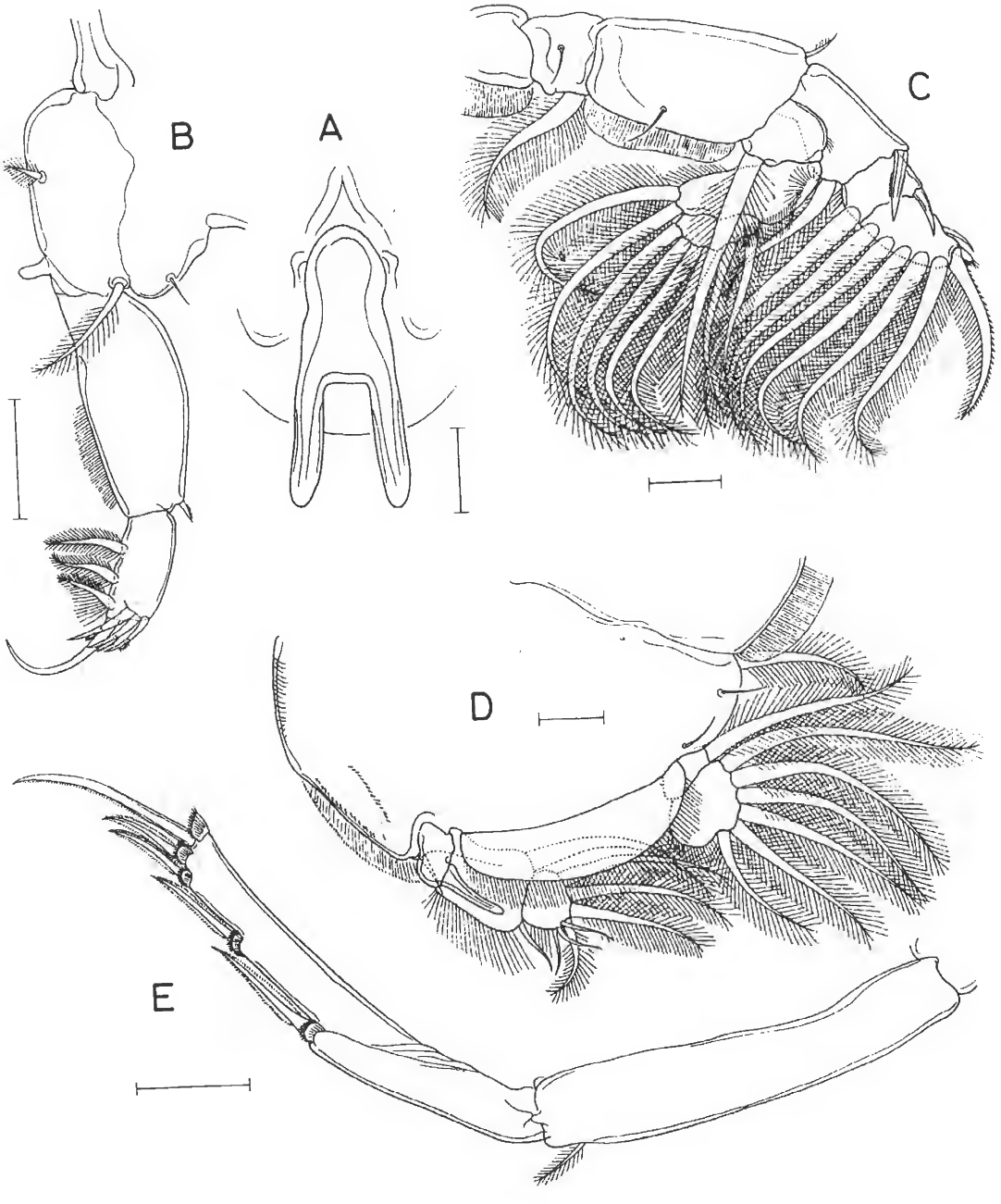

Figure 2. ***Caligus chelifer*****, adult male: A. sternal furca; B. leg 1; C. leg 2; D. leg 3; E. leg 4. Scales A-E= 0.1 mm.**

bear a triangular genital complex, with a distinctly slender and inward directed caudal rami. The main differences between these two species are found in the shape of the cephalothorax, which is narrower in *C. chelifer* (the 3 setae on exopod inner margin are relatively shorter in *C. chelifer*), and in the spine on the first exopodal segment of leg 3, which is quite broad in *C. praetextus*. *Caligus productus* is also related to *C. chelifer*; both share a 4-segmented leg 4 with three apical setae (in *C. chelifer* the first one is twice as long as the other two, while in *C. productus* the first seta is only slightly longer). Neither of these species show lateral processes of sternal furca, and the fourth exopodal seta of leg 1 terminal segment is much longer than the remaining three (in *C. chelifer* the third seta is relatively longer than in *C. productus*). Both species differ in the structure of the maxilliped and the marginal ornamentation of leg 2 endopod.

Although the host of our specimen of *C. chelifer* remains unknown, this species has been collected from three fish species that occur in the Gulf of Mexico (Hoese and Moore 1977): the Atlantic cutlassfish (*Trichiurus lepturus* Linnaeus 1758), a menhaden (*Brevoortia gunteri* Hildebrand 1948) and a swordfish (*Xiphias gladius* Linnaeus 1758) (Wilson 1905). Other records are from off Miami, and from *Brevoortia tyrannus* (Latrobe 1802), collected off Port Aransas, Texas (Cressey 1991). *Caligus chelifer* has not been reported south of 25°N. The present record represents the first record of this species in Mexican waters and allows a southward extension of its known latitudinal distribution into the tropical zone of the Northwestern Atlantic.

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Gulf Coast Research Laboratory: A Mississippi Academy

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GULF COAST RESEARCH LABORATORY: A MISSISSIPPI ACADEMY OF SCIENCES PROJECT THAT HAS COME OF AGE[1]

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ABSTRACT A brief overview of the creation and growth of the Gulf Coast Research Laboratory, this article traces the institution's history and its strong relationship with the Mississippi Academy of Sciences. The Mississippi Academy of Sciences officially dedicated the Gulf Coast Research Laboratory (GCRL) with the opening of the first summer session at Magnolia State Park in Ocean Springs, Mississippi, on August 28, 1947. Mississippians in scientific and educational circles had worked for two decades toward creating a research and educational laboratory focused on the state's marine and coastal environments. The Academy's priorities were scholarly research and education. Political leaders' were interested in the potential for a direct effect on the economy of Mississippi. The evolution of that two-fold focus has created a unique institution that integrates scientific discovery with graduate, undergraduate and public education as well as with rapid and effective response to questions of public concern.

On August 28, 1947, the Mississippi Academy of Sciences officially dedicated the Gulf Coast Research Laboratory (GCRL) with the opening of the first official summer session at Magnolia State Park in Ocean Springs, Mississippi. That event marked the culmination of more than two decades of effort by Mississippians in scientific and educational circles who had seen the need for a research and educational laboratory focused on the marine and coastal environments of Mississippi. The future of the fledgling laboratory would also be influenced by local and state political leaders who saw the new facility as an institution that would allow for "the investigation of the propagation, life histories, control and protection of marine organisms now proving to be of commercial value in the coastal areas." GCRL emerged with several purposes. The highest priority for the Academy was scholarly research and education. For political leaders the priority was research that was expected to have a direct effect on the economy of Mississippi (Bailey 1995).

The evolution of the two-fold focus of scholarship versus immediate impact set into motion a creative tension still at work today as GCRL administrators, researchers, and educators merge sometimes contrasting missions, approaches, priorities and perspectives. GCRL scientists, their graduate students and their technical staff explore fundamental questions about the plants, animals and processes of Mississippi's marine environments. At the same time, they have a firsthand relationship with the practical realities and the concerns encountered by the people who live, work and play in those environments. The result is a unique institution that integrates scientific discovery with graduate, undergraduate and public education as well as with rapid and effective response to questions of public concern.

Institute of Marine Sciences

The present-day Gulf Coast Research Laboratory is a component of The University of Southern Mississippi's Institute of Marine Sciences. In March 1996, Mississippi's Board of Trustees of the Institutions of Higher Learning created the Institute by merging the Laboratory, GCRL's J.L. Scott Marine Education Center and Aquarium, and the former USM Center for Marine Sciences at Stennis Space Center. GCRL is located on a 50-acre site in Ocean Springs and is adjacent to the Mississippi Sound. The campus is surrounded by bayous and salt marshes that provide a natural laboratory for researchers and students. GCRL's 21 buildings house research and teaching laboratories, classrooms and offices where more than 160 researchers, technical and support personnel, and graduate and undergraduate students work.

The Laboratory is home to the Gunter Library, one of the most extensive marine science libraries in the northern Gulf of Mexico region. The Laboratory's Ichthyological Research Collection includes more than 200,000 fish specimens from around the world. Among the Laboratory's vessels are the R/V *Tommy Munro*, a 97-foot oceanographic research vessel; the 38-foot wooden trawler, the M/V *Bill Demoran*; and the 38-foot steel M/V *Hermes*.

On the Laboratory's Biloxi campus, the J.L. Scott Marine Education Center & Aquarium houses Mississippi's largest public aquarium and features marine educational programs and firsthand experiences for Mississippi residents

[1]This history commemorates the 50th anniversary of the founding of the Gulf Coast Research Laboratory. The article first appeared in the Journal of the Mississippi Academy of Sciences 42(4):183-192, September 1997.

and visitors of all ages. More than 75,000 children and adults visit the Center each year. Approximately 30,000 of the Center's yearly visitors are involved in the hands-on education programs that have earned the Center an international, award-winning reputation. The facility's 48 aquariums, arranged around the 42,000-gallon Gulf of Mexico tank, showcase native creatures typical of Mississippi's waters from freshwater streams to open ocean.

The third component that has joined the Laboratory as part of the Institute is USM's Marine Science Program located at the Stennis Space Center near Bay St. Louis, Mississippi. The concentration of oceanographic and space agencies at Stennis affords IMS faculty scientists, science educators, researchers, and graduate and undergraduate students opportunities to establish collaborative relationships among nearly 4,000 scientists, engineers and technical personnel. The Maury Oceanographic Library, one of the world's largest, and two super computers located at Stennis comprise a valuable part of the infrastructure that supports the IMS oceanography program.

Research at GCRL focuses in five major areas: marine aquaculture, biodiversity and systematics, coastal ecology, environmental fate and effects, and fisheries science. Complementing these research areas are those of the Marine Science Program at Stennis: paleoceanography, carbon and nutrient cycling in coastal environments, modeling the ocean and its systems, wave-current interactions, phytoplankton ecology, marine community dynamics, hydrology, antarctic ecosystems, and marine chemistry.

Early Days

The breadth of the Gulf Coast Research Laboratory's programs had its beginnings in the vision of Missisippians prior to World War II. An early Gulf Coast Research Laboratory bulletin identified Mississippi State College professors as first planting the seeds for the emphasis of the Laboratory's educational focus:

"The earliest attempt to establish a Laboratory on the Gulf Coast, according to Dr. Clay Lyle, Head of the Department of Zoology and Entomology of Mississippi State College, was initiated by his predecessor, Dr. R. W. Harned. Dr. Lyle stated that he has found in his files correspondence which indicated that considerable effort was made during the early 1920s by Dr. Harned and Col. H.D. Money of Biloxi, Mississippi, to establish a Research Laboratory on the Coast."

State Geologist Dr. H.M. Moore actively promoted the idea in the Academy, and a coastal research laboratory was regularly a matter of discussion in business sessions of the organization. Academy member R.L. Caylor, later appointed first director of the Gulf Coast Research Laboratory, was using the Mississippi Gulf Coast as a laboratory for his summer field courses.

Robert J. Bailey, in his *History of the Mississippi Academy of Sciences: It's First Fifty Years*, said of Caylor's activities: "It is appropriate to point out at this time that an energetic biology professor at what was then Delta State Teachers College conducted summer field schools on the Mississippi Gulf Coast in 1935 and 1937. He addressed the 1938 annual meeting on 'Some Research Possibilities along the Mississippi Gulf Coast.' His name was R.L. Caylor, and his work was certainly a forerunner of the Laboratory."

Caylor also conducted field trips to the Coast in the summers of 1940 and 1946. The Delta State professor and a group of 20 students made Magnolia State Park, now part of the Gulf Islands National Seashore, their headquarters for the 1946 field course. The Academy accepted an invitation to hold a special session at Magnolia State Park. Bailey chronicled the session that started on August 15, 1946:

"After several days of intensive discussion, an ad hoc committee was established and charged with the responsibility of studying the feasibility of establishing a marine research and teaching laboratory. . . On August 23, 1946, the committee offered its proposal that the Academy should establish GCRL."

The Academy membership approved a resolution on May 2, 1947, in the annual regular meeting to take the steps needed to establish the Gulf Coast Research Laboratory:

> Whereas the Mississippi Academy of Sciences desires to further its work in promotion of scientific research, and to establish and maintain a laboratory on the Mississippi Gulf Coast to be known as the Gulf Coast Research Laboratory; It is hereby resolved that in order to meet the need of incorporation of the Mississippi Academy of Science, Dr. Clyde Q. Sheely, Dr. Ray J. Nichols, Dr. Clytee R. Evans, Dr. Charles L. Deevers, Dr. W.E. Riecken, and Professor John M. Frazier be appointed and authorized by the Mississippi Academy of Science to apply to the Secretary of State of the State of Mississippi for a charter of incorporation, such corporation to be known as the Mississippi Academy of Sciences, Incorporated.

The Academy's 1947 meeting minutes also show the appointment of a Gulf Coast Scientific Research Laboratory Committee. The nine members included the incorporation committee members with the addition of Caylor, G.N.

McIlhenry and E.G. Breu. The charter of incorporation of the Mississippi Academy of Sciences, Incorporated was recorded in the records of incorporation of the Mississippi Office of the Secretary of State on July 23, 1947. The charter was the Academy's "business license" to establish and maintain a scientific research laboratory and to conduct the financial and other activities necessary to accomplish that purpose. Academy members had discussed incorporation of the Academy as early as 1939.

"In 1947, it became a reality, and the impetus for the Academy's incorporation was the creation of R.L. Caylor's and others' long-hoped-for Gulf Coast Research Laboratory (GCRL)," Bailey recounted. Caylor and the Academy considered the 1947 summer session as the first GCRL class of summer students. Twenty-six students and three staff members participated in the two-week session at Magnolia State Park.

Caylor also pushed the creation of the Laboratory with the Mississippi Board of Trustees of the Institutions of Higher Learning. In a May 5, 1997, letter prompted by the faculty and staff celebration of GCRL's 50 years, former IHL official J.L. Scott of Jackson recalled Caylor taking the laboratory idea to the IHL.

"A science professor, Dr. R.L. Caylor from Delta State Teachers College, came by the Board office in the late summer . . . and talked to the Executive Secretary of the Board, Dr. E.R. Jobe, about establishing a center on the Coast to be used by the Mississippi Academy of Sciences. The graduating students who were going into the schools as teachers could not identify marine life or semi-tropical plant life that they would be teaching about in the high schools.

"Dr. Jobe and I agreed with Dr. Caylor. We discussed the idea with Board members and concluded that this would enhance the [state's] science programs. The Board directed that we find a suitable site and report back for final action. This search for a suitable site was an easy task. Since we [the IHL] had no funds the Magnolia State Park was the best location."

Scott recalled the Board of Trustees was in favor of the preparation of a bill establishing a Laboratory on the coast and in the Magnolia State Park. Board member John Savage of Gulfport and Jobe comprised the committee charged with composing the bill. Scott worked with the committee to draft the legislation. The 1948 session of the Mississippi Legislature approved the bill, stipulating that the Laboratory be located on Magnolia State Park property, that it be operated by the Mississippi Academy of Sciences under the supervision and control of the Board of Trustees of the Institutions of Higher Learning, and that the Board of Trustees expend out of the IHL appropriation a sum not to exceed $5,000 annually [Miss. Code Ann. § 37-101-19 (1997)].

GCRL enthusiasts forged ahead in spite of obstacles. Scott described the old Civilian Conservation Corps buildings—the living facilities for summer session participants—as a "semi-camp out." He rounded up buildings and equipment valued at $260,000 through the Federal Security Agency.

"We acquired 'surplus property' equipment for a dining area and kitchen, and other furniture just to exist. In 1949 our dining hall burned in the middle of the night. We were never able to determine the cause of the fire, but were convinced that this was not the best location for the laboratory."

Bailey noted that it was apparent that the Magnolia State Park site was not sufficient for the Laboratory's expected growth and expansion. "Further, the State Building Commission turned down numerous requests for funds to construct new facilities for the Laboratory or reconstruct surplus equipment and buildings, which had been pledged to the Academy and the college board by the Federal Security Agency," Bailey recorded.

GCRL advanced another step on February 11, 1949, when the IHL established the research laboratory as "a separate and independent institution of higher education and research in Mississippi to be operated by the Mississippi Academy of Sciences." Soon after that IHL action, negotiations turned serious for purchase of the present location, property just across the bayou from Magnolia Park that had recently become available. Bailey's history describes this property as the former estate of D.A. Smart, who at one time was an editor of *Esquire* magazine. Under consideration was the 39-acre site that included a large two-story house — affectionately

The "Big House"—One of the original structures of the GCRL property.

The attic of the "Big House" was reserved for staff members to create and repair the nets needed for sampling the waters of the Gulf of Mexico and Mississippi Sound.

termed "the Big House" by later Laboratory employees, a garage apartment, a greenhouse, an artesian water well, 1,600 feet of beach front, two 36-foot boats and dock facilities. The Laboratory's broad support was evident in the negotiations. Participating were Academy members, IHL Board of Trustees President Martin V.B. Miller, the Jackson County Board of Supervisors under the leadership of Board President Fred Moran of Ocean Springs, state legislators from the coast and the Ocean Springs Chamber of Commerce (Howse 1992).

Support by the State Building Commission remained limited, much to the frustration of Caylor and his colleagues. Jobe, IHL executive secretary, led the Academy to press home points likely to garner support with the commission and the state legislature:

1. that the Academy recognized that it was not in a financial position to assume full control of the Laboratory;
2. that it was willing for IHL to assume full responsibility for the operation and maintenance of the facility;
3. that the MAS would be content to serve in an advisory role;
4. and that the MAS would not support the concept that the Laboratory should come under the jurisdiction of any one senior college or university.

The state increased support and purchased the Smart property for $35,000. The 1950 session of the Mississippi Legislature approved a bill that established the Laboratory as a corporate entity within state government, operating under the administration of the IHL and located within the state on the Gulf of Mexico [Miss. Code Ann. § 37-101-19 (1997)]. As the first director, Caylor continued to work toward establishing adequate physical facilities.

"He never let a week pass that he did not call me for help on needed equipment or facilities," Scott said. "Dr. Caylor's requests came before the Board so often that at one of the meetings Mr. Charles Fair, the president of the Board instructed Dr. Jobe not to worry about putting the requests on the agenda. 'Just let Jake do it.' From then on I just reported monthly what I had done for and with the GCRL."

As Scott shepherded the acquisition and construction, he joined the ranks of Caylor, numerous Academy members and individuals in the public and private sectors who developed a passion about the marine laboratory and devoted exceptional personal and professional effort to its survival and growth. Scott recalled the day that Mississippi Governor Hugh White came on board to support construction at the present-day site.

"Governor Hugh White insisted that he make all building commission trips to university and college campuses. This was part of the inspection of buildings and review requests for new buildings. The trip to GCRL was scheduled for August. We had requested funds for erection of two buildings for dormitory use. Materials had been salvaged from Pascagoula, the old shipyard cafeteria and theater building. Governor White always wore a white linen suit in summer. He and I walked out to the neatly stacked pine lumber. He sat on a stack of 2x6 timbers, and we talked about using this for our buildings. When he decided to get up, his white linen pants were stuck on the resin, and you could just hear it coming loose. Of course I apologized and offered to take them to the cleaners. He looked at me and said, 'Scott, I have been in the lumber business all my life. That is a sign that this is good lumber.' Needless to say, we received funds for the buildings."

Bailey noted that, although Caylor recognized that the immediate need for buildings could be met inexpensively with surplus lumber, he insisted that a long-term building program begin. He and the Academy's Laboratory committee met to discuss such construction with an architect (Bailey 1993).

ACADEMICS

While Caylor and Laboratory supporters worked to create a physical plant, the director and his colleagues of the Academy were building the summer academic program. Caylor's report to the Academy in 1951 reflects their progress. The first three summer sessions—1947, 1948 and 1949—were all located at Magnolia State Park. The second session, held in 1948, was expanded to four weeks with 52 students and 5 staff participating. The final session at Magnolia Park was a six-week session in 1949 with 57 students and 9 staff. The first summer session held on the

Bill Demoran, first full time research scientist to join the GCRL staff, signed on with Dr. A.E. Hopkins, director, in 1952.

current property was 10 weeks with 54 students and 7 staff (Caylor 1951-53). In the early days of the Laboratory, summer classes were held outside under cover of the trees (Howse 1992). Gordon Gunter, the Laboratory's third director, recalled a visit to the facility long before his tenure as director. "I remember what a lush, dank, seaside it was, where people worked on rough, wooden tables, under the trees" (Gunter 1971).

In an earlier report to the Academy, Caylor captured that "under the trees" pioneer spirit of the Laboratory's educational programs, programs that continue to ignite a passion for marine science in students of all ages today. He noted that a visiting lecturer from the Texas A. and M. Research Foundation stated his impressions of the Laboratory in an address before the 1948 summer Laboratory group. A striking aspect to him was that "with no coercion professors and students from nearly every school in the state are working side by side, all moving in the same direction." Caylor continued, "The Laboratory operated briefly last summer, offering courses in Botany, Geology, and Zoology . . . It will operate for a longer period in 1949, offering courses in Zoology, Botany, and Geology with the addition of courses in Science for the Elementary and High School teacher" (Caylor 1948-50).

Caylor held annual meetings of Academy officers and faculty representatives from Mississippi senior colleges to plan each summer's program (Walker 1974). "The Mississippi Academy of Sciences was very active in promoting and manning the GCRL summer schools in these early years," Scott said. "There were so many Academy members who devoted complete body and soul to teaching in the summers."

Faculty and students immediately started modest research efforts, gathering specimens as a foundation for a museum collection and a preliminary inventory of the organisms of Mississippi coastal waters. Faculty were also working with taxonomists from around the U.S. on identification of the organisms (Walker 1948-50).

The budding education and research efforts were enhanced in 1950 with the Laboratory's association with the Mississippi Seafood Commission. The Commission assigned the research vessel *Uranus* to the Laboratory for the summer. Much of the early construction activity was also a result of the association with the commission. In 1952, the time had come for a 12-month laboratory, and A.E. Hopkins, an advisor to the seafood commission and head of the commission's research program, was appointed GCRL director. Caylor remained director of the summer academic program. The move to a year-round operation opened the door for a permanent staff. Hopkins and Jackson County Senator Hermes Gautier also teamed up and successfully secured state funding for construction of a teaching laboratory and the acquisition of a research vessel.

Caylor submitted his resignation as director of the Laboratory's educational program at a December 1953 meeting of the Academy's Gulf Coast Research Laboratory Committee. In a tribute to Caylor at the Academy's April 23-24, 1954, meeting, President C.E. Lane, Jr., said, "To hundreds of students he has been the Gulf Coast Laboratory just as much as the classrooms, the boat trips, and the permanent buildings one will see there. In Dr. Caylor's own words, he stayed with the Laboratory until it could be put on a permanent year-round footing. Now that this is done, he feels that he can return to summer teaching in his

Computer Power — The old GCRL computer occupied an entire room in the late 1960's

own department at Delta State College with the assurance that the course work and research of the Laboratory will continue" (Sheely 1948-50).

Hopkins, an aquatic biologist specializing in oysters, hired William Demoran, now retired, as a second full-time staff member. "We both went to work on July 1, 1952," Demoran said in an article in the Pascagoula *The Mississippi Press* (Hines 1997). Following Hopkins death in 1954, Caylor was appointed interim director for the 1955 summer program. Dr. Gordon Gunter was appointed director in 1955 and served as director until 1971. He continued his association with the Laboratory as professor of zoology and director emeritus until his retirement from active service with the State of Mississippi in 1979 at the age of 70.

A native of Louisiana, Gunter had earned his Ph.D. from the University of Texas and had served as director of the University of Texas Institute of Marine Science at Port Aransas before coming to Gulf Coast Research Laboratory. Under Gunter's leadership, the Laboratory experienced a growth surge in the 1960s with the construction of modern buildings and the expansion of scientific staff. Construction added more than 79,000 square feet of laboratories, office space for scientific staff, classrooms and student housing. Many of the Laboratory's major buildings became a reality during Gunter's tenure as director: the Oceanography Building, the 40-room brick dormitory currently in use, the Anadromous Fisheries Research Laboratory, the R.L. Caylor Building, the maintenance shop, renovation of the A.E. Hopkins Building and the Research Building. The Laboratory's first large research vessel, the 65-foot R/V *Gulf Researcher*, was also completed in 1964.

James S. Franks, Larry C. Nicholson, Harriet M. Perry and Richard S. Waller, all current IMS scientific staff and fisheries biologists employed initially by Gunter, gathered at the Gunter home in Ocean Springs on August 14, 1997, for an American Fisheries Society awards ceremony. They presented the American Fisheries Society's half-century membership award to Gunter. He and his former staff members shared memories of the Laboratory's earlier days. The reminiscences continued after the visit ended.

"He is one of the great naturalists living today," Nicholson said. "He is interested in every living thing — how each species affects other species and how natural processes affect them — understanding how everything is connected."

Demoran recalled that the Laboratory launched its first major research project shortly after Gunter became director. "In 1956, we got the first contract to do serious research, a $22,000 grant to study menhaden in the Gulf of Mexico." Gunter had brought a biologist with him that increased the staff to three. An additional staff member and a boat captain were hired once the menhaden project was a reality (Hines 1997).

As he built the scientific staff, Gunter also marshaled the essential tools for a scientist's work. High on his list of priorities was access to the scientific literature. He laid the foundation for one of the best collections of marine science publications in the Gulf of Mexico region. He established *Gulf Research Reports*, the scientific journal of marine sciences for the Gulf of Mexico and adjacent waters. *Gulf Research Reports* has published continuously since 1961.

Sustained state funding was limited, and "he donated many of the volumes for the library from his own collection," Perry said. Waller recalled that Gunter's regular practice was to accept consulting work for which he commanded remarkable fees even by today's standards. He then used the fees to buy equipment or books for the library. "One of his reasons for starting *Gulf Research Reports* was to establish an exchange relationship so that our library would receive scientific journals," Waller said.

CAMILLE

Natural forces battered the Laboratory's progress when Hurricane Camille struck in August 17, 1969. In Hines' *Mississippi Press* article, toxicologist David Burke recalled he had been with the Laboratory only 14 months when the killer storm swept ashore. "We thought it was probable that we would never recover, the destruction was so complete," Burke said. "It was summer time and we had a campus full of kids. For a 10-day period nobody could get in or out," he said. Administrative Officer Robert Ochsner made certain the students were safe. "He had no idea his

The morning after Hurricane Camille, Dr. Gordon Gunter and Dr. Walter Abbott stand on the spot where the "Big House" stood.

home and family in Gulfport had survived. He stayed put and got his work done and got word back to frantic parents that their kids were all right," Burke said.

Burke cited Charles Dawson, who was section head of systematic zoology, for his leadership at that time. Dawson started the staff on the task of rolling up copper wire while he looked for a generator. He also organized the massive cleanup needed in the wake of the storm's devastation.

The response to the storm was characteristic of the staff. "We all pitched in and helped. If somebody needed help, we did it. It gave you a better insight in the field of marine science. It was a learning process" (Hines 1997).

Modern Times

The academic program continued to expand through the mid-70s. Gunter worked with colleague Harry Bennett, a former professor and dean at Louisiana State University, to put the process in place for out-of-state colleges and universities to become affiliates of the Laboratory and accept credits earned by their students at GCRL. LSU became the first of the more than 60 institutions now affiliated with the Laboratory.

Under subsequent directors Drs. Harold Howse (1972-89) and Thomas L. McIlwain (1989-94), GCRL expanded in the areas of research, public service and education. GCRL researchers continued exploring fundamental questions about Mississippi's marine resources while public service activities increased. Federal and state agencies tapped the scientific expertise at the Laboratory, contracting with GCRL to explore specific problems and opportunities related to marine resources, to craft fisheries management plans, and to put proposed solutions into effect. A number of benchmark works published by researchers during this period are still in demand today by other scientists, educators and students. While academic program enrollment dipped for a period in the mid-70s, GCRL public and pre-college education efforts expanded dramatically with the opening of an environmental education center in 1972. The facility on Point Cadet in Biloxi was the precursor of the present J.L. Scott Marine Education Center & Aquarium which opened on Point Cadet in 1984. By the late 1980s the educational programs at the center were serving as models for marine and environmental programs for teachers and students far beyond Mississippi's borders. The original environmental education center remains in use today, providing additional classroom space as the MEC&A Annex. The academic summer program also rebounded and by the early 1990s was straining classroom and dormitory facilities.

The Laboratory's relationship with the Academy remained strong through the years. GCRL's first director served as president of the Academy in 1949. Five additional past presidents of the Academy have been Gulf Coast Research Laboratory directors or scientists. GCRL scientific staff members have been active in committees and other facets of the Academy.

Further organizational changes have come to GCRL in the past decade. In 1988 the Mississippi Board of Trustees of the Institutions of Higher Learning placed the Laboratory under the administrative oversight of The University of Southern Mississippi. Following Director McIlwain's retirement, Dr. Donald R. Cotten served briefly as interim director. Dr. Robert T. van Aller served as interim director from 1994 through 1996 while continuing as USM's graduate dean. Following a national search, Dr. D. Jay Grimes was appointed director of both the Gulf Coast Research Laboratory and the Institute of Marine Sciences, coming on board in January of 1997. A microbiologist specializing in marine organisms, Grimes' research administration experience includes directing the New Hampshire Sea Grant College Program and the U.S. Department of Energy's microbial genome and bioremediation programs. His research and administrative experience have made him a strong proponent of the integrated activities that characterize GCRL: a combination of basic and applied research, rapid transfer of technology for public and economic benefit, formal graduate and undergraduate education, and precollege and continuing education.

He sees the future of GCRL and the Institute as limited only by availability and conditions of work space. In a recent interview he cited GCRL as a key component in the growth of the IMS as a leader in providing science-based solutions to economic and environmental challenges facing Mississippi and other coastal states of the Gulf of Mexico.

"Gulf Coast Research Laboratory is no newcomer," Grimes said. "GCRL has been here for 50 years. The people and priorities of GCRL are major factors in my certainty that we will fulfill the vision of the Institute as the preeminent marine sciences institution on the Gulf of Mexico."

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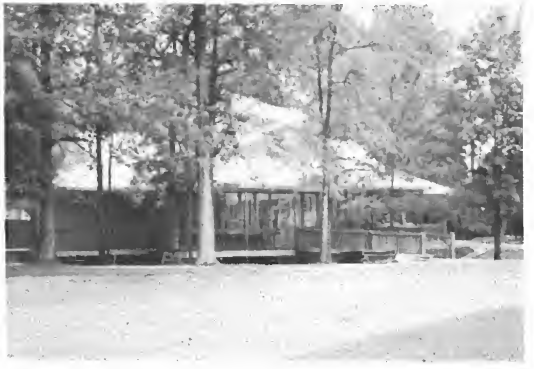
The small building to the left of the old dining hall was an aviary, one of the original existing buildings at the time the state purchased the present laboratory site. The building, used for a greenhouse by the first botanist on staff, was swept away by Hurrican Camille. The dining hall was torn down in 1996.



The present dining hall is the newest of the buildings on the GCRL Campus.

GCRL's 97-foot oceanographic vessel, the R/V *Tommy Munro*

Richard L. Caylor
Director 1948-1952

Aubrey E. Hopkins
Director 1952-1954

Gordon Gunter
Director 1954-1971

Harold D. Howse
Director 1972-1989

Laboratory leadership from
1948-1997

Thomas D. McIlwain
Director 1989-1994

Donald R. Cotten
Acting Director 1994

Robert T. van Aller
Acting Director 1994-1996

D. Jay Grimes
Director 1997 to present

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Gulf Estuarine Research Society Spring 1998 Meeting Abstracts

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GULF ESTUARINE RESEARCH SOCIETY

SPRING 1998 MEETING

The Spring 1998 meeting of the Gulf Estuarine Research Society (GERS) is to be held from Thursday, March 26 through Saturday, March 28, 1998, in Galveston, Texas. Meeting sessions will be held at the HOLIDAY INN ON THE BEACH located at 5002 Seawall Blvd. The meeting is being hosted by the National Marine Fisheries Service Galveston Laboratory. Local contacts for the meeting are Lawrence Rozas (409-766-3532; lawrence.rozas@noaa.gov) and Pete Sheridan (409-766-3524; pete.sheridan@noaa.gov).

Tentative Schedule

Thursday, March 26	4:00 pm - 8:00 pm	Registration at Holiday Inn (HI)
	7:00 pm - 9:00 pm	Reception at NMFS Lab
Friday, March 27	8:30 am - 11:45 am	Registration and Sessions at HI
	1:00 pm - 4:30 pm	Sessions
	5:00 pm - 6:30 pm	Poster Session at HI
	7:00 pm - 12:00 pm	BBQ Bash - Knights of Columbus
Saturday, March 28	8:30 am - 11:00 am	Sessions at HI
	11:00 am - 12:30 pm	Student Awards and Business

Abstracts

The following abstracts were received by January 5, 1998; and these papers will be presented at the meeting by authors whose names are underlined. Special presentations also will be given by Harold Stevenson (Publishing and the Editorial Process of *Estuaries*), Chris D'Elia (Federal Budgeting and Success in the Grant Process), and Gene Turner (Estuarine Signatures for the Gulf of Mexico).

Cannon, Andrea Caron. National Marine Fisheries Service, Galveston, TX. **SEA TURTLE STRANDINGS AND CAPTURES FROM GALVESTON BAY.** Since 1991, four of the five species of sea turtles found in the Gulf of Mexico (Kemp's ridley, loggerhead, green, and hawksbill) have been reported in Galveston Bay. All turtles that are reported to the Sea Turtle Stranding and Salvage Network (STSSN) are documented. Dead turtles are recovered and necropsied, while live turtles are brought to the National Marine Fisheries Service Sea Turtle Research and Rehabilitation Facility for rehabilitation. Dead strandings make up the majority of the reports (85%). Due to the condition of the carcasses, a definitive cause of death is rarely determined. These carcasses are still important sources of life history data (sex ratios, food sources and feeding habits). Few of the reported turtles are alive (15%). Generally it is known why the turtle stranded alive (cold stunned, caught on power plant intake screen, injured post hatchlings, or caught by recreational hook-and-line); however, there are still unknown causes.

Childers, Daniel L.[1], Nicholas J. Oehm[1], Frank Parker[1], and Christopher Madden[2]. [1] Southeast Environmental Research Program & Department of Biological Sciences, Florida International University, Miami, FL, and [2]Everglades Systems Research Division, South Florida Water Management District, West Palm Beach, FL. **HOW FRESHWATER EVERGLADES WETLANDS MEDIATE CHANGES IN WATER FLOW AND NUTRIENT LOADINGS TO THE FLORIDA BAY ESTUARY.** Everglades restoration efforts are focusing on large-scale changes in water delivery to Everglades wetlands. These changes include increased water inputs, and associated changes in nutrient regimes, in a freshwater-estuarine system that we are currently studying in eastern Everglades National Park (ENP). In 1997, a levee was removed from along the major drainage canal that delineates the northern boundary of this ENP Panhandle region in order to increase sheetflow through these wetlands and to Florida Bay. Between this canal and the estuary, wetlands range from sawgrass marsh to mixed *Cladium-Rhizophora* wetland to scrub red mangrove forest, respectively. Our ENP Panhandle sampling began in Fall 1997, at which point over half of the levee had already been removed. We established a wetland transect roughly normal to the canal and behind the remaining levee. Throughout the remaining 1997 wet season, we sampled water overlying the sawgrass marsh along this transect both intensively (every 3 hours for 48 hours) and extensively (every 2 days continuously). Approximately halfway through our sampling, levee removal was completed. Our water chemistry data from before and after levee removal show that nutrient concentrations in wetland surface water more than doubled after removal of the levee, from about 0.2 to 0.4 5M TP and from about 45 to 140 5M TN. When combined with the large increase in wetland sheetflow from the new inputs of canal water, this represents a significant increase in nutrient loading to the ENP Panhandle wetlands and perhaps even to the Florida Bay estuary. However, the sawgrass marsh within 3 km of the canal appears to be removing much of this nutrient load. Interestingly, this wetland uptake phenomenon did not immediately show up as increased porewater nutrients in these wetlands. Furthermore, cores taken before and after levee removal show an inhibition of C mineralization (via aerobic respiration, sulfate reduction, and methanogenesis) in wetland soils receiving increased canal inflows; this in spite of the fact that C decompositional processes in Everglades wetland soils are strongly phosphorus limited. We have not yet observed any changes in soil porewater salinities or sawgrass productivity since the levee was removed and sheetflow increased, but we would anticipate a significant lag in response by such parameters—and levee removal was only completed in late October 1997. We will continue to quantify these parameters over the next 3 years, along 2 parallel transects. Additionally, we will extend our transects through the mangrove wetland zone and to the Florida Bay confluence, and we will construct and sample replicate flumes immediately adjacent to the canal edge, to more accurately quantify nutrient uptake and transformations by the sawgrass marsh. Thus, our research will continue to quantify how freshwater wetlands in the ENP Panhandle region are mediating the quantity and quality of additional water inflow that reaches the Florida Bay estuary, in response to Everglades restoration efforts.

Davis, Stephen E., III and Daniel L. Childers. Department of Biological Sciences / Southeast Environmental Research Program, Florida International University, University Park Campus, Miami, FL. **SEASONAL VARIATION IN CONCENTRATION AND FLUXES OF CARBON, NITROGEN, AND PHOSPHORUS IN TWO SOUTH FLORIDA MANGROVE FORESTS.** Since August 1996, we have been conducting quarterly sampling studies to determine the flux of carbon (C), nitrogen (N), and phosphorus (P) between dwarf and fringe red mangrove (*Rhizophora mangle* L.) wetlands and their associated water column along Taylor River in Everglades

National Park. We constructed modified, duplicate, in-channel flumes and triplicate, dwarf mangrove island enclosures (3-5 m in diam.) to determine these wetland-water column interactions. Total N, TP, TOC, and DOC concentrations were highest in the early wet season while dissolved inorganic N (DIN) concentrations peaked during the transition from wet season to dry season. Soluble reactive P concentrations fluctuated greatly (0.01-0.1 µM) both during and between samplings and were usually highest in the dwarf zone. Dwarf mangrove islands have shown a consistent pattern of DIN export (2-50 µmoles m-2 hr-1) for all samplings except August (NOX import) and November 1996 (NOX export and NH4 import). Control enclosures—which contain no mangroves—reflected this DIN release in May 1997 but showed significant uptake of both NOX and NH4 in August 1997. The fringe mangrove has shown a pattern of DIN uptake for nearly every sampling. We observed a significant release of SRP during the wet season of 1996 (0.1-3.8 µmoles m-2 hr-1) and release of TP in November 1996 and May and August 1997 (0.1-2.1 µmoles m-2 hr-1). There was no clear pattern of P flux in the fringe forest. Organic C fluxes were greatest of all constituents (+/- 3500 µmoles m-2 hr-1). Although DOC makes up roughly 95% of TOC in our system, we observed different flux behaviors for each of these constituents. The fringe forest appeared to take up organic C (especially DOC) during most of the samplings. The dwarf forest imported TOC during the dry season (100-1250 m-2 hr-1) and then exported it during the wet season (50-3300 µmoles m-2 hr-1). The dwarf forest imported TN in both August (early wet season) samplings (20-500 µmoles m-2 hr-1) and exported TN in May 1997. The fringe forest showed a pattern of TN uptake for all samplings. Additional data to be analyzed will come from November 1997 and January 1998 samplings. This project is part of a larger study looking at the importance of water source: freshwater (Everglades) vs. marine (Florida Bay) in controlling nutrient flux in the microtidal mangroves of the SE Everglades. During the wet season, direct precipitation and the freshwater marshes to the north are the major sources of water and nutrients, and during the dry season, Florida Bay is the source. Our data suggest a seasonal trend in both the concentrations and fluxes of these water-column constituents.

Devlin, Donna J. Department of Biology, University of Southwestern Louisiana, Lafayette, LA. **A FIELD EXPERIMENT OF PREDATOR STRATEGIES AND MANGROVE RESISTANCE: THE RELATIONSHIP BETWEEN THE RED MANGROVE (*RHIZOPHORA MANGLE*) AND THE SCOLYTID BEETLE *COCOTRYPES RHIZOPHORAE*.** Predation on propagules and seedlings is an important biological factor affecting the mix of mangrove seedlings on the forest floor and may partially determine which individuals recruit into the canopy. Unlike in the Indo-Pacific and parts of the Caribbean where many species of Grapsid crabs are important seedling predators on red mangroves (*Rhizophora mangle* L.), the primary *Rhizophora* propagule and seedling predator in Florida is the scolytid beetle *Cocotrypes rhizophorae*. This beetle is a borer and excavates extensive brood chambers in the seedlings. Eggs are laid within and all life history stages of the beetle exist together in the seedling. *C. rhizophorae* requires red mangrove seedlings or occasionally adult aerial root tips for completion of its life cycle. In a field experiment in southwestern Florida, I studied two important questions about this predator-prey relationship. First, does the predator mainly employ a *colonization strategy* by infesting *R. mangle* propagules before they drop from the parent tree, thereby ensuring that they could use the floating propagules as a vector to establish new populations; or, a *stay-at-home strategy* by infesting propagules after they strand and root in a forest, and thus ensure an environment relatively safe from being washed out to sea? Second, are propagules from some parent trees more susceptible to predation and mortality than those from other trees. This, along with the species-specific nature of the infestation, could affect the mix of species and genotypes of *R. mangle* in the seedling population and potentially influence recruitment of trees into the canopy. The experiment involved assigning propagules collected from 20 parent trees to both the canopy and forest floor under 15 recipient trees. At 2 weeks infestation was much greater on the ground than in the canopy (chi square test, p=0.001). Using randomization techniques, I determined that there were also among-parent tree differences in seedling survival of infestation (p=0.01). Therefore the beetle may be affecting the genetic diversity of *R. mangle* populations in forests where beetle densities are high.

Engelhard, Tannika and Kim Withers. Center for Coastal Studies, Texas A&M University-Corpus Christi, Corpus Christi, TX. **BIOLOGICAL EFFECTS OF MECHANICAL BEACH RAKING IN THE UPPER INTERTIDAL ZONE ON PADRE ISLAND NATIONAL SEASHORE, TEXAS.** During late spring and summer, beaches on Padre Island National Seashore (PINS) receive large quantities of stranded macrophytic algae, primarily *Sargassum* spp. (Phaeophyta, Fucales). PINS employs mechanical raking as a public-use management practice for removal of beach wrack to improve the aesthetic and recreational quality of the beach for visitors. This study was undertaken to determine

biological effects of mechanical raking in the upper intertidal zone and to make recommendations concerning the use of mechanical raking for wrack removal. Four sites along Malaquite Beach on PINS were systematically sampled from May through September 1997. Two treatments were applied, weekly and biweekly raking. Samples were collected on Day 3, 7, 10 and 14 following raking (Day 0). Avian abundance, macrofaunal abundance and biomass and sediment parameters (Chlorophyll , %TOC and % water) were determined for raked and unraked areas and analyzed using a two factor ANOVA. Results indicated that the dominant invertebrate macrofauna could be grouped into benthic organisms (*Haustorius* sp. and polychaetes) and organisms associated with wrack material (*Orchestia grillus* and insects). Both groups were affected by mechanical raking to some extent. The greatest differences between raked and unraked sites occurred within three days following raking with mean density and biomass significantly higher in unraked areas for all macrofauna. On Day 7 and 10, mean density and biomass was significantly lower at raked sites only for *O. grillus* and polychaetes. No significant differences existed between raked and unraked areas on Day 14. Sediment parameters exhibited no significant differences between sites for any days. Since differences in sediment conditions can be excluded as the primary source of variation, it was concluded that macrofaunal density and biomass decreased due to raking either by direct removal or as a result of vertical migration into the sand column in response to disturbance caused by raking. Bird abundance was not significantly different between raked and unraked sites during the study. Management recommendations were made based on the effects of raking on macrofaunal abundance, avian use and public visitation trends.

Engelhaupt, Erika[1], Thomas S. Bianchi[1], Matt Tarr[2], and Robert G. Wetzel[3]. [1] Department of EEO Biology, Tulane University, New Orleans, LA, [2] Chemistry Department, University of New Orleans, New Orleans, LA, and [3] Department of Biological Sciences, University of Alabama, Tuscaloosa, AL. **EFFECTS OF ULTRAVIOLET RADIATION ON THE COMPOSITION AND MICROBIAL UTILIZATION OF DISSOLVED ORGANIC CARBON (DOC) IN BAYOU TREPAGNIER, LA.** Light, particularly ultraviolet radiation, is known to release biologically available organic substrates from refractory materials such as humic substances. For example, Wetzel et al. (1995) found that in dissolved organic matter (DOM) released from senescent littoral aquatic plants, exposure to natural UV radiation resulted in the release of many small fatty acids. Furthermore, these fatty acids were readily metabolized by bacteria and resulted in increased bacterial protein productivity. However, few studies of photolysis of DOM have examined this process in the field, partly due to restrictions such as finding a site with a consistent hydrologic regime but varying light regime, where direct comparisons of the effects of UV can be made. The long hydraulic residence time, variable light regime, and high DOC concentrations of Bayou Trepagnier make it an ideal location to study UV photolysis of dissolved organic carbon (DOC) in a natural system. DOC values range from 15-100 mg L^{-1}, much higher than typical riverine or estuarine concentrations. Light values range seasonally from 68 to 150 mmol m^2 s^{-1} in a shaded site dominated by *Lemna minor* cover, while values at a non-shaded site range from 605 to 1650 mmol m^2 s^{-1}. A significant percentage of DOC is represented by colloidal organic carbon (COC; < 0.2 microns and > 1 kDa), ranging from an average of 27% in August to 56% in November 1997. COC is collected seasonally using cross-flow ultrafiltration from both field sites and irradiated in a solar simulator for 24 hours (the equivalent of about 4 sunny summer days) with both UV-A (315-400 nm) and UV-B (280-315 nm) light. To determine changes in functional groups of COC after irradiation, both irradiated and non-irradiated samples from both sites are compared using ^{13}C NMR spectroscopy. Preliminary analyses of ^{13}C NMR spectra of COC indicate relative abundances of aromatic and carboxylic/carbonyl functional groups of 40 – 60% and 20 – 25%, respectively. In addition, further work will include field measurements of bacterial protein productivity using ^{3}H leucine incorporation and bacterial abundance by direct counts.

Garber, Nikola M., Walter D. Grater, and Kenneth C. Stuck. Institute of Marine Sciences, Gulf Coast Research Laboratory, Ocean Springs, MS. **APPLICATION OF THE MITOCHONDRIAL DNA CONTROL REGION IN POPULATION STRUCTURE STUDIES OF GREY MULLET (*MUGIL CEPHALUS*) IN NORTH AMERICA.** In animal eukaryotic cells, a small amount of DNA is found outside the nucleus within the mitochondria. This mitochondrial DNA (mtDNA) evolves independently and at a faster overall rate than nuclear DNA. Specific genes and the non-coding control region within the mtDNA also evolve at different rates and can therefore be used in phylogenetic, systematic, and population level genetic studies. The non-coding control region is the most rapidly evolving segment in mtDNA and been used to distinguish populations of marine fish. Grey mullet, *Mugil cephalus*, has a worldwide distribution and is common

in coastal waters of the continental United States and Hawaii. Because of declining numbers, a program has been implemented in Hawaii to enhance natural mullet populations through release of cultured stocks. Similar enhancement efforts have been proposed in Mississippi. Therefore, studies have been initiated to determine the population structure of grey mullet in North America and Hawaii using direct sequence analysis of the mtDNA control region. Polymerase chain reaction (PCR) and universal primers to conserved regions of the mtDNA which flank the control region were used to produce a 2000bp fragment. The fragment has been cloned and sequenced, and internal primers have been designed to amplify the hypervariable portion of the control region. These procedures, which have been developed in the initial phase of this study, will be used to conduct future population genetic studies with mullet.

Gorham-Test, Cynthia. U. S. Environmental Protection Agency, Region 6 (6WQ-EW), Dallas, TX. **THE 1993 REGIONAL ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM (R-EMAP) STUDY OF GALVESTON BAY, TEXAS.** The Regional Environmental Monitoring and Assessment Program (R-EMAP) Study of Galveston Bay, Texas addresses the ecological health of this estuary by identifying benthic community structure, measuring toxicity of sediments, and measuring concentrations of various pollutants in the sediments. The Sediment Quality Triad approach was used in this study to differentiate between degraded sites and undegraded sites. For comparison of the main body of Galveston Bay with other systems and the Louisianian Province as a whole, twenty-nine randomly selected sites were chosen to represent 1305 km^2 of the Galveston Bay System. Random sites are located in Galveston Bay, Trinity Bay, East Bay and West Bay. In addition, a sample was taken for each of four important small bays associated with Galveston Bay, and for five marinas. This study does not include an analysis of the upper Houston Ship Channel, the Trinity River, or any other major tributaries. The Benthic Index, the Benthic Diversity Index, and abundance of Amphipods at each site proved useful in demonstrating that communities living in contaminated sediments had a community structure indicating poor conditions. The proportions of the two indices in the Galveston Bay area were similar to the proportions reported for the Louisianian Province in the 1993 EMAP Study. In contrast, amphipod occurrence in Galveston Bay sediments was significantly lower than in the entire Louisianian Province sediments. A degraded Benthic Component was found at 7 of 29 randomly sampled sites in Galveston Bay and 8 of 9 Small Bay & Marina Sites. Toxicity was seen when using amphipods as a test organism, but toxicity was not reported when using mysid shrimp. Toxicity results reveal a low occurrence of acute toxicity in Galveston Bay sediments. In Galveston Bay, arsenic, copper, lead, nickel, and zinc exceed the ERL but not the ERM criteria at one or more sites sampled. Sites with the most metals contamination include Offatt's Bayou, Clear Lake, Moses Lake/Dollar Bay, and two Marina sites. All of these sites are "Small Bay and Marina sites", which were chosen, not randomly selected, so they are not included in comparisons of Galveston Bay with the Louisianian Province 1993 EMAP sampling area. However, several of the randomly sampled sites in Galveston Bay did have exceedences for arsenic, chromium, nickel, and zinc. Exceedences of chromium, copper, lead, nickel, and zinc for each site were almost always due to anthropogenic inputs and not natural sources. Heavy metal concentrations greatly influenced the determination of degraded sites for the Sediment Chemistry Component of the Triad. TBT concentrations are higher in Galveston Bay sediments than expected with values greater than 1 ppb occurring in 52% of the area, compared to 31% of the total Louisianian Province area. A significant relationship exists between butyltin concentrations in the sediments and butyltin concentrations in the water column. Sites with high Dieldrin and Endrin concentrations in the sediments are located in upper Galveston Bay, Clear Lake, and upper Trinity Bay. PAHs exceeding ERL values in Galveston Bay include only C3-fluorene at one site in Trinity Bay where several active oil wells are located. Distributions of PAHs for Galveston Bay show that three sites, one site in Trinity Bay and two sites near Texas City in West Bay, have PAHs that are considerably higher than at the other sites in the Galveston Bay. The major variables used to determine degraded sediment chemistry in Galveston Bay include metals, butyltins, PAHs, pesticides other than DDTs, and silt-clay content. These variables were compressed into one factor (PPPMO) using Principal Components Analysis. Most of the degraded sites were "Small Bay & Marina sites" which were not randomly selected and which were near areas of high human activity. Most of the open bay area sites were in a marginal or healthy condition. The most degraded areas in the Galveston Bay Complex include seven Small Bay and Marina sites and five randomly chosen sites in the open bay: Offatt's Bayou, Clear Lake and its marina sites, Lafayette Landing and South Shore, Upper Galveston Bay at the Houston Yacht Club, Moses Lake/Dollar Bay and Trinity Bay near the river mouth, and mid-East Galveston Bay. Major tributaries, such as the Upper Houston Ship Channel and the Trinity River, were not sampled in this study.

Henderson, Christine. Texas A & M University at Galveston, Marine Laboratory, and National Marine Fisheries Service, Galveston, TX. **FACTORS AFFECTING THE COMMUNITY COMPOSITION OF EPIBENTHIC AND INFAUNAL INVERTEBRATES OF NEWLY PLANTED SEAGRASS BEDS.** Epibenthic and infaunal organisms represent an important link between macrofauna and the seagrass beds they utilize. For this reason, benthic organisms should be considered when a comparison is made of the structural and functional equivalency of planted beds and natural seagrass beds. Three *Halodule wrightii* beds were planted during May 1994 in western Galveston Bay, Texas. The experimental design allowed for evaluation of water depth, planting density, and distance to edge on benthic community composition. Bare sand adjacent to the planted sites and a natural seagrass bed 15 km southwest of the planted sites were used for comparison. Monthly cores 10 cm diameter by 5 cm deep were taken for 16 months after beds were planted. Excluding decapods, invertebrates were identified to species when possible. Although species richness and abundance within the planted seagrass beds increased relative to adjacent sands, epibenthic and infaunal communities did not closely emulate those of the naturally occurring seagrass bed. Preliminary data indicate planting density had a positive effect on faunal densities, while water depth and distance to edge had no effect. Planted seagrass beds often take 2-3 years to reach shoot and root densities comparable to those of naturally occurring beds. Benthic communities in planted beds probably take at least as long to reach structural equivalence with those in natural seagrasses.

Lambert, C. D. [1], T. S. Bianchi [1], G. C. Flowers [2], and G. L. McPherson [3]. [1] Department of EEO Biology, [2] Department of Geology, [3] Department of Chemistry, Tulane University, New Orleans, LA. **THE EFFECTS OF COLLOIDAL ORGANIC CARBON (COC) ON THE FATE AND TRANSPORT OF HEAVY METALS IN BAYOU TREPAGNIER, LOUISIANA.** Cycling dynamics of dissolved organic carbon (DOC) were examined in Bayou Trepagnier, Louisiana, in relation to its role in the partitioning of heavy metals (Pb, Cr, Zn, and Cu). Bayou Trepagnier is part of the Lake Pontchartrain estuarine system and is influenced by changes in lake water levels from tidal and wind forcing. Bayous, which are low energy systems with long hydraulic residence times, are common in the southern regions of the United States and are unique, in that they act as "chemostats" for the breakdown of natural organic matter in sediments and soils. DOC concentrations ranged from 5 to 100 mg C/liter with highest concentrations following the diversion of the Mississippi River to the Lake Pontchartrain estuary. The percentage of DOC represented by COC (< 0.2 microns and > 1 kDa) ranged from 20 to 60% in the water column; pore water DOC concentrations ranged from 65 to 200 mg C/liter with COC comprising 40 to 80 % of the DOC in pore waters. Preliminary analyses of C-13 NMR in COC showed a relatively high abundance of aromatic (40 to 60%) and carboxylic/carbonyl (20 to 25%) functional groups which have been shown to be influential in the partitioning of heavy metals onto colloidal particles. Seasonal profiles of functional groups common in natural organic matter will be discussed. Metal concentrations of Pb, Cr, Zn, and Cu ranged from 0.5 to 10 ppb, 0.8 to 10 ppb, 2 to 40 ppb, and 0.4 to 70 ppb, in the particulate phase, respectively, while metal concentrations in the colloidal phase ranged from 0.6 to 18 ppb, 0.5 to 9 ppb, 2 to 25 ppb, and 0.2 to 3.6 for Pb, Cr, Zn, and Cu, respectively. High metal concentrations in the colloidal phase suggested that DOC and COC plays an active role in the partitioning of metals, especially in regions where DOC is extraordinarily high.

Miller-Way, Tina [1] and Robert R. Twilley [2]. [1] University of Mobile, Mobile, AL and [2] University of Southwestern Louisiana, Lafayette, LA. **OXYGEN AND NUTRIENT METABOLISM OF A CARIBBEAN MANGROVE PROP ROOT COMMUNITY.** Fringe mangrove communities are highly productive despite low nutrient concentrations in surrounding waters. As in coral reef communities, high rates of production may be maintained by intense rates of nutrient recycling. This study determined nutrient exchange and oxygen consumption rates for the dominant heterotrophic members of the mangrove prop root communities of Twin Cays, Belize. Rates were measured using closed system incubation techniques under in situ conditions. Water column nutrient concentrations were determined for sites near and far from prop root communities to corroborate microcosm results. Three of the 6 species examined (*Tedania ignis*, a sponge, *Distaplia corolla*, a tunicate, and the mangrove oyster, *Isognomon alatus*) were significant sources of NH4 to surrounding waters (1.32 - 22.47 µmols g dry wt-1 hr-1). In contrast, the sponges, *Ulosa rutzleri* and *Lissodendoryx isodictyalis* released no NH4 but were a significant source of NO3 to surrounding waters (0.15 - 14.78 µmols g dry wt-1 hr-1), probably due to symbiotic associations with nitrifying bacteria. Stoichiometric ratios and transect data indicate that this 'new' nitrogen is not lost from the system through denitrification. The sponge, *Tedania ignis*, was also a source of PO4 to surrounding

waters (0.06 - 0.21 µmols g dry wt-1 hr-1). The anemone, *Aiptasia pallida*, was not a significant source or sink for oxygen or nutrients within the community but this pattern may be misleading due to the presence of zooxanthellae within its tissues. Considering their high weight specific rates and high biomass, sponges are responsible for most of the oxygen consumption of the mangrove prop root community. These data suggest that the prop root community may be a metabolic 'hot spot' for nutrient regeneration and oxygen consumption within the fringe mangrove ecosystem.

Mitra, S. [1] and R. M. Dickhut [2]. [1] Department of EEO Biology, Tulane University, New Orleans, LA, and [2] School of Marine Science, Virginia Institute of Marine Science, Gloucester Point, VA. **POLYCYCLIC AROMATIC HYDROCARBON (PAH) DISTRIBUTION COEFFICIENTS IN SEDIMENTS FROM AN URBAN ESTUARY: THE ROLE OF PAH SOURCE AND SEDIMENT GEOCHEMISTRY.** Sediments and pore waters from two sites (Site 1 & Site 2) in the urbanized Elizabeth River, VA were sampled for levels of polycyclic aromatic hydrocarbons (PAHs) as well as several geochemical variables. Pore water PAH concentrations were similar between both sites, despite an order of magnitude higher sediment PAH concentrations at Site 2. Organic-carbon normalized distribution coefficients (K'OCs) for all PAHs were also higher at Site 2 compared to Site 1, but decreased substantially with depth in the sediments at Site 1. Dilute sedimentary soot carbon, and other geochemical factors potentially affecting PAH distributions, including sediment age, grain size, particle surface area both before and after organic digestion, concentrations of lignin/phenols, and organic carbon / nitrogen ratios were also analyzed. Different factors were determined to control particle surface area at each site offering the most insight to explaining observed PAH K'OCs. At Site 1, increased mineral surface area is related to overall lower K'OCs and sediment PAH concentrations, and decreased downcore PAH K'OCs. We hypothesize that sediment organic matter becomes increasingly inaccessible with depth at this site. At Site 2, large and invariant K'OCs appear to be the result of sediments comprised of woody debris coated with natural dissolved organic matter or creosote, sequestering PAHs within the particle matrix. PAH isomer concentration ratios, indicators of differential PAH sources, mirrored trends in PAH distribution coefficients lending support to these arguments. Our results indicate there is significant heterogeneity in PAH distribution coefficients in estuarine sediments, which may be attributable to localized PAH sources and sediment geochemistry.

Moncreiff, C. A., T. A. Randall, J. D. Caldwell, R. K. McCall and B. R. Blackburn. University of Southern Mississippi, Institute of Marine Sciences, Gulf Coast Research Laboratory, Ocean Springs, MS. ***GYMNODINIUM BREVE*** **IN MISSISSIPPI SOUND:** A PATTERN FOR PREDICTION? *Gymnodinium breve* was first observed in water samples collected in Mississippi Sound north of Petit Bois Island on 31 October 1996. Blooms spread north from the barrier islands to oystering areas, forcing reef closures. A combined drop in surface salinities and water temperatures ended the event. Detection and monitoring of this species began with charter boat operators, who reported unusual fish behavior south of the barrier islands on 26 October 1996 and collected a water sample; microscopic examination confirmed the presence of this species, first in this sample from south of the barrier islands, and then in additional samples collected as the bloom progressed from the vicinity of barrier islands to waters overlying actively harvested oyster reefs. Subsequent analyses of oyster tissues confirmed the presence of brevetoxins at significant levels. *Gymnodinium breve* is reported to bloom at somewhat higher salinities than those observed during this event, which suggests that the hypothetical "salinity barrier" for this species may be lower than studies have previously suggested. Suspended sediments may also inhibit bloom development. Seasonally collected turbidity and salinity data indicated that the former of these two parameters was significantly different in 1996 when compared to similar data for 1994 and 1995, which may have contributed to conditions conducive to the spread and development of this toxic algal species within Mississippi Sound. Examination of surface water temperatures via data buoy records showed the arrival of a warm water mass in the northern Gulf of Mexico in early October, which may have contained sufficient *G. breve* cells for bloom initiation and development. Surface water movements in October and November of 1996 as tracked through Minerals Management Service's Drifter program also provides a mechanism for delivery of this toxic bloom species to the northern Gulf from the west coast of Florida. Red tides are a natural occurrence, and are an integral component of the estuarine ecosystem and its cycles that we are still trying to understand. Human impacts on the environment, such as increased levels of nutrients in coastal waters, may be related to an increase in the number of these blooms of algae as a whole, but is apparently unrelated to this particular occurrence of *Gymnodinium breve*.

Osborn, Timothy [1], Erik Zobrist [1], Rickey Ruebsamen [1], and Van Cook [2]. [1] National Marine Fisheries Service and [2] Louisiana Department of Natural Resources. **WETLANDS CREATION AND LARGE WETLANDS RESTORATION EFFORTS OF THE NATIONAL MARINE FISHERIES SERVICE WITHIN THE COASTAL WETLANDS PLANNING, PROTECTION AND RESTORATION ACT PROGRAM IN COASTAL LOUISIANA.** Within the Coastal Wetlands, Planning, Protection and Restoration Act (CWPPRA), the National Marine Fisheries Service (NMFS) and the Louisiana Department of Natural Resources (DNR) have forged a Federal/State partnership to plan and implement a significant number of large wetland restoration projects spanning the state's coastal zone. Each project was competitively evaluated within the CWPPRA Task Force in the annual Priority Project Selection process. In describing the CWPPRA program and the NMFS/DNR partnership, a case study is instructive. The following is a synopsis of the Big Island Restoration Project. The Big Island project, sponsored by the National Marine Fisheries Service, is located in Atchafalaya Bay about 18 miles southwest of Morgan City, Louisiana. It is in the western half of the lower Atchafalaya River delta and encompasses the shallow bay area to the north and west of Big Island. Natural expansion of the Atchafalaya River delta (Atchafalaya Bay about 18 miles southwest of Morgan City, Louisiana) has been hampered by the deposition of material dredged from the Federal navigation channel. The Big Island project will restore freshwater and sediment delivery processes to the northwestern portion of the delta. Project implementation will create nearly 500 acres of deltaic wetlands and allow natural delta growth which, over 20 years, is expected to create an additional 1,300 acres of wetland habitat. The project entails the construction of distributary channels having a combined length of about 24,000 feet, extending from the Atchafalaya River into the shallow waters west of Big Island. Dredged material will be placed in a pattern to mimic natural delta lobes and to create conditions conducive to trapping of riverine sediments and deltaic expansion. In addition to this, implementation of the Atchafalaya Sediment Delivery project, on the eastern side of the Federal Navigation channel, will restore freshwater and sediment delivery processes to the northeastern portion of the delta. Project implementation will create nearly 300 acres of deltaic wetlands and allow natural delta growth which, over 20 years, is expected to create an additional 1,700 acres of emergent and submergent wetland habitat. The project entails the construction of two distributary channels having a combined length of about 11,000 feet, extending from the East Pass channel, through Natal Channel and Radcliffe Pass, and into the shallow waters east of the existing delta. Dredged material will be placed in a pattern to mimic natural delta lobes and to create conditions conducive to trapping of riverine sediments and deltaic expansion. Presently, approximately twelve projects within the CWPPRA program are sponsored by the NMFS with a cumulative project area in excess of 70,000 acres. With the hopeful continuation of the program, the NMFS will continue to develop and implement additional projects benefitting Louisiana and the nation.

Proffitt[1], C. E. and D. J. Devlin[2]. [1] Louisiana Environmental Research Center, McNeese State University, Lafayette, LA and [2] Department of Biology, University of Southwestern Louisiana, Lafayette, LA. **SURVIVAL, GROWTH, AND SUCCESSION IN A RESTORED MANGROVE STAND IN SOUTHWESTERN FLORIDA.** In 1982, fill was removed from three dredge spoil mounds at the Windstar development in Naples and the sites were planted with red mangrove (*Rhizophora mangle*) propagules on 1 m centers. In 1989, 84.6% of the area of the northern site was covered by mangroves. Most of this was a relatively tall (>2 m) thicket ("tall mangrove" plots) and the rest was sparsely populated with shorter (<1.5 m), scrubby mangroves ("scrub plots"). In 1989, the site was dominated by white mangroves (*Laguncularia racemosa*) with density range of 2.1±1.6 to 12.9±1.4 trees/m^2. Black mangroves (*Avicennia germinans*) had colonized at low densities (greatest densities: 1.4±0.6 trees/m^2). Densities of *R. mangle* were 0.7±0.7 to 2.9±1.4 trees/m^2 and, along with the spatial pattern, indicated these trees originated from the propagules planted in 1982 with little subsequent colonization. During 6 mo. in spring and summer of 1989, total stem growth of marked stems was significantly greater in scrub plots than in tall mangrove plots for both *R. mangle* (means: Scrub plots 180.0 mm; tall plots 15.7-46.0 mm) and *L. racemosa* (means: Scrub 182.7 mm; tall 38.0-59.4 mm) There was no significant difference among plots in total stem growth of *A. germinans*. Combining scrub and tall mangrove plots, stem growth was greatest, although highly variable, in *A. germinans* (219.3±352.4 mm) relative to *R. mangle* (69.9±147.7 mm) and *L. racemosa* (92.3± 146.7 mm). Leaf production showed the same general patterns. Beginning in 1995, many *L. racemosa* in tall mangrove plots died and others showed signs of stress. Mortality was the greatest where starting *L. racemosa* densities had been the highest with these plots showing a 78% decrease in *L. racemosa* live trees and concomitant increases in standing dead trees in 1996. This was correlated with decreasing light penetration as the canopy became more closed. Prior to 1989, growth in scrub plots had obviously been slow and survival reduced. However, from 1989-1996 all 3 species showed greatest growth in height and trunk

diameter in scrub plots, and, by 1996 canopy heights in scrub plots were not significantly different from those in tall mangrove plots. In scrub plots, this accelerated tree growth was accompanied by colonization and increased densities of saplings and trees of *R. mangle* and *L. racemosa*. This may have been due to decreases in adverse environmental conditions with increasing tree size and canopy cover.

Powers, Sean P. Texas A&M University at Galveston, Marine Laboratory, Galveston, TX. **SUPPLY-SETTLEMENT RELATIONSHIPS IN AN ESTUARINE FOULING COMMUNITY.** Understanding the processes which are responsible for species distribution and abundance is a central goal of community ecology. Over the last 15 years, researchers of marine benthic systems have increasingly focused on the potential role of water column supply of new recruits and settlement (*e.g.* "recruitment limitation" and "supply-side ecology") in determining species distribution and abundance. The majority of this research has been conducted in temperate rocky intertidal areas or tropical reef systems; few studies have examined this question in sub-tropical encrusting communities. For a 9 month period in 1993-94, I monitored supply, settlement, and recruitment of six species of invertebrates in the fouling community of a tidal lagoon on Galveston Island, Texas. Water column supply of new recruits was monitored using passive plankton collectors and settlement/recruitment was monitored using 100 cm^2 gray PVC panels. Each collector consisted of a 0.75 m^2 concrete base with three pieces of reinforcing rod (rebar) placed at the corners. A 60 cm long, 5 cm diameter plastic tube was attached to each rod. The tube had an internal formalin layer which allowed *in situ* preservation of particles deposited in the trap. The tube provides a measure of the flux of passive particles passing over the opening; increases in either the horizontal advection or concentration of particles results in increase flux. Three stations were established in the center of East Lagoon along a gradient of decreasing water flow, i.e. station 1 > station 2 > station 3. From June 1993 to February 1994, three tube samples and two settlement panels were collected at each station every two-three weeks. Larvae and juveniles from the tube samples and settlement panels were identified to the lowest practical taxa and counted. In order to answer the question of whether the supply and or settlement of each taxon varied over space or time, abundances of new recruits in the water column (collectors) and settlers (panels) for each of the six species were analyzed using a two factor ANOVA with date and station location as effects. Second, I used correlation analyses to determine if supply and settlement showed any relationship. Finally, regression analysis was used to examine the relationship between settlement and the biomass of the panel (a surrogate measurement for structure). The strength of the relationship between supply and settlement varied among the taxa examined. Water column supply of larvae was a good predictor of settlement and recruitment for only one species, *Balanus eberneus*. Correlation coefficients of the supply/settlement relationship for *B. eberneus* ranged from 0.77 to 0.92 during the study. Correlation coefficients for the other five taxa examined were below 0.5. For the polychaete *Polydora ligni* and nematodes, the amount of suitable structure available appeared to be the limiting factor in explaining settlement. A strong positive relationship (r^2 > 0.72) was found between settlement and the biomass of barnacles on the panels. For other taxa, *i.e.* the amphipod *Corophium sp.*, the polychaetes *Hydroides dianthus* and *Neanthes succinea*, and the flatworm *Stylochus frontalis*, neither factor showed a strong relationship with settlement. The processes which determine recruitment success for communities are highly taxa specific and involve both pre and post-settlement factors. While larval supply can be an important determinant of settlement in some taxa (e.g. barnacles), the amount of suitable structure can be equally important in others (e.g. *Polydora ligni* and nematodes). Still in some taxa, neither appears to be the determining factor in recruitment into the community. Clearly, multiple processes are needed to explain recruitment in many multi-species assemblages.

Randall, T. A., C. A. Moncreiff, J. D. Caldwell, and R. K. McCall. University of Southern Mississippi, Institute of Marine Sciences, Gulf Coast Research Laboratory, 703 East Beach Drive, Ocean Springs, MS 39566-7000 **SEAGRASS RESOURCES IN MISSISSIPPI SOUND: PAST AND PRESENT.** The current and historical distributions of seagrasses in Mississippi Sound were mapped to provide a usable form of baseline information for this valuable marine resource. Seagrass distributions from a 1969 Gulf of Mexico estuarine inventory were used as a source of historical documentation, while data from a 1992 National Biological Survey aerial imagery study were ground truthed to provide recent distribution patterns. Potential seagrass habitat was also identified using a 2 meter critical depth limit, previously established by others and one of the authors (CAM) in a National Park Service seagrass monitoring project. The continued survival and growth of seagrasses may be threatened by the cumulative effects of anthropogenic activities in the coastal marine environment, which include commercial and recreational

use of seagrass habitat, in addition to a number of other uses which may directly or indirectly impact seagrasses. The primary vector for the disappearance of seagrasses is presently thought to be an overall decline in water quality, which may have a deleterious effect on certain species of seagrasses. Detailed maps of extant seagrasses and potential seagrass habitat are critical because of their importance as nursery habitat for larval and juvenile stages of fish and invertebrates, many of which are economically important. Because seagrassses and their associated microalgae function as both habitat and food for better-known organisms such as penaeid shrimp and blue crabs, in addition to many non-commercial species that often directly or indirectly support commercial fisheries, it is imperative that we elucidate how these critical habitats function. The maps generated from this study will be used to compare the historical extent of the seagrass communities with present day coverage. This baseline information will aid resource managers and scientists in recognizing and interpreting the effects of potential degrading impacts on the seagrasses and will lead to informed decisions regarding the management of this marine resource.

Rozas, Lawrence P. and Thomas J. Minello. National Marine Fisheries Service, Galveston, TX. **RELATIONSHIPS BETWEEN SEDIMENT HYDROCARBON CONCENTRATION AND SALT MARSH HABITAT USE IN GALVESTON BAY.** We sampled nekton, benthic infauna, and sediments in salt marsh habitats at ten locations in upper Galveston Bay, Texas to examine relationships between habitat use and sediment hydrocarbon concentration. Sample locations included marshes heavily oiled in the past as well as areas that were relatively clean. We estimated nekton densities in fall 1995 and spring 1996 by collecting five samples at each location using a 1-m^2 drop sampler. We estimated benthic infaunal densities at each sample site from three pooled 5-cm diameter cores. We also measured salinity, water temperature, dissolved oxygen concentration, water depth, marsh elevation, distance to marsh edge, plant stem density, and turbidity at each site; and sediments at each site were analyzed for grain size, organic content, and petroleum hydrocarbon concentration. Total petroleum hydrocarbon (TPH) and TPH fractions (i.e., "medium" (MPH) and "heavy" HPH) were determined by the Institute for Environmental Studies at Louisiana State University using gas chromatography/ mass spectrometry. We tested the null hypothesis that there is no relationship between sediment hydrocarbon concentration and use of the marsh surface by nekton and infauna using two types of analyses. We examined potential relationships between animal abundance and sediment hydrocarbons by simple linear regressions of organism densities against sediment TPH and MPH concentrations. We further explored potential relationships between animal density and sediment hydrocarbon concentrations by including ten independent variables (environmental parameters measured at each site) in addition to either TPH or MPH in a Stepwise Multiple Regression Analysis. Although most marsh sediment samples were contaminated with oil, most samples contained relatively low concentrations of weathered petroleum hydrocarbons. We found potential relationships between animal density and TPH concentration for very few animals. Of 63 abundant taxa (31 nekton and 32 infauna) examined, only six showed a significant negative relationship with sediment TPH levels. As evident from the low R^2's for the models in each case, petroleum hydrocarbon levels in sediment could account for only a small portion of the variability in animal densities for these taxa. In Stepwise Multiple Regression Analyses, hydrocarbon concentration did not contribute significantly to the models for most taxa; and in most cases where TPH or MPH were important variables, the relationship was positive (i.e., animal densities increased with TPH values). The low hydrocarbon concentrations in the sediments of upper Galveston Bay marshes could have contributed to our results either because levels were too low to be toxic or levels were toxic but too low to be detected by most organisms. Our study provides essential baseline data on sediment TPH and animal densities in shoreline marshes of upper Galveston Bay that have a high probability of being impacted by oil spills in the future. The data from our study will be useful in assessing the impact of any future spills in this part of Galveston Bay.

Salter, Michelle R., L. Harold Stevenson and C. E. Proffitt. Louisiana Environmental Research Center, McNeese State University, Lake Charles, LA. **LABORATORY MICROCOSM FOR TESTING MICROBIAL DEGRADATION OF VENEZUELAN CRUDE OIL.** Oil exploration, production, transportation, and refining along the Gulf Coast present the potential for pollution problems in sensitive estuarine habitats. Bioremediation represents a viable strategy for the mitigation of the damage done by the release of petroleum hydrocarbons in these areas. The usefulness of 10 cm X 17.5 cm, 1 L sediment columns as microcosms to test variables associated with bioremediation was examined in a series of laboratory experiments. To be useful, microcosms must meet several criteria. First, the design for the microcosm must allow for the collection of samples for studies of both redox potential and microbial populations. Second, the columns must serve as replicates within the experimental design showing no statistically significant

differences between columns used in the same treatment. Third, microcosms must be sustainable without either algae productivity or oxygen diffusion from the surface disrupting anaerobic conditions within the column. Fourth, redox potentials within the columns should mimic that of the natural environment. Each of the above expectations was tested in a separate mini-experiment to determine the feasibility of the use of columns in future bioremediation studies. Data were analyzed using one and two way ANOVA as appropriate. The final design did allow for the easy collection of samples. The individual microcosms showed no significant difference ($p = 0.098$) when most probable numbers of bacteria were compared, allowing the columns to be used as replicates. Over a fifteen day period there was no significant difference between elutant portions of the column ($p = 0.749$) which allowed different samples taken from the same column to also be used as replicates. There was, however, a significant decrease in Eh ($p = 0.0005$) showing that algae growth and oxygen diffusion from the surface was minimal if taking place at all. A redox potential at or near 50 mV was aimed for in order to mimic a natural Louisiana brackish marsh. This was obtained with the addition of 3% ammonium sulfate and sodium acetate solution ($p = 0.0005$). Therefor, the conclusion was made that the developed microcosm was a useful tool for testing variables associated with bioremediation in a laboratory environment.

Scott-Denton, Elizabeth. National Marine Fisheries Service, Galveston, TX. **UTILIZATION OF SUBMERGED AQUATIC VEGETATION HABITATS BY FISHES AND DECAPODS IN THE GALVESTON BAY ECOSYSTEM, TEXAS.** Fish and decapod densities in shoalgrass, *Halodule wrightii*, wigeongrass, *Ruppia maritima*, and adjacent non-vegetated sand or mud habitats in Galveston Bay, Texas were compared to determine the relative value of each habitat in terms of faunal utilization and species richness. Physical, environmental and other biological variables for each habitat were examined in relation to faunal density. Fish and decapod densities were quantitatively sampled during fall, spring and summer using a $1 m^2$ throw trap. Totals of 48 taxa and 8,163 individuals were collected from 204 m^2 throw trap samples (equally divided between vegetated and non-vegetated habitats) taken during the period 30 September 1993 to 28 November 1994. Vegetated habitat (*Halodule* and *Ruppia)* contained 89% of the total fauna by number (83% decapods; 17% fishes), with non-vegetated substrate (sand and mud) containing 11% (55% decapods; 45% fishes). The dominant species in vegetated habitats were daggerblade grass shrimp, *Palaemonetes pugio*, 40%; blue crab, *Callinectes sapidus*, 15%; and white shrimp, *Penaeus setiferus*, 12%. Dominants in non-vegetated habitats included *Penaeus setiferus*, 21%; *Callinectes sapidus*, 16%; and gulf menhaden, *Brevoortia patronus*, 14%. The amount of submerged aquatic vegetation (SAV) cover appeared to be the most important variable related to total fish and decapod densities. Significant differences in faunal densities indicated that SAV habitat was more valuable to fishes and decapods than non-vegetated substrate. Non-vegetated substrate adjacent to SAV, however, was utilized by some species including commercially important *Penaeus setiferus*. Total faunal densities were similar between *Halodule* and *Ruppia* each season, but there were seasonal variations in use of each habitat at the species level, particularly by some commercial and recreational species. *Halodule* and *Ruppia* appear to function as "essential fishery habitat", as defined by the Magnuson-Stevens Fishery Conservation Act of 1996, and should be conserved to maintain fishery productivity.

Sheridan, Pete. National Marine Fisheries Service, Galveston, TX. **TRAJECTORY FOR STRUCTURAL EQUIVALENCE OF RESTORED AND NATURAL *HALODULE WRIGHTII* BEDS IN TEXAS.** Habitat restoration seeks to promote disturbed habitats toward structural and functional equivalency with natural areas. We examined several components of seagrass beds to determine the time needed to reach structural similarity. Flora, fauna, and sediments of five restored *Halodule* beds were compared to those in adjacent natural beds over several years. Tests of functional equivalency were not conducted but are needed both here and elsewhere. Seagrass beds (< 1 m depth) were located near Corpus Christi or Galveston, Texas and had been restored between 1988 and 1994. Three beds were spoil island scrape-downs that were transplanted, one was a scrape-down that re-vegetated naturally, and one was a shoreline transplant. Beds were examined 2 to 6 times each to derive patterns for ages 0.25 to 8.1 yr. Synoptic estimates of seagrass coverage (using quadrats or transects) were made only during the first 1 to 4 years post-restoration, as required and recorded by the permitting agency (Texas General Land Office). Quantitative sampling gear was used to estimate seagrass shoot and root/rhizome biomass, root : shoot ratios, sediment organics, sand : silt : clay ratios, and densities of fishes, decapods and benthos. Ten replicate samples with each type of gear were collected from each bed pair during each visit. Seagrass coverage in restored beds usually exceeded 60% in < 2 yr but may never reach that of natural beds due to construction anomalies. Planners left berms and channels (not found in natural seagrass beds) that trap debris and prevent seagrass expansion. There is some variation in coverage speed, in that one site had not reached the legal requirement of 70% after almost 3.5

yr. Seagrass biomasses in restored beds, both above- and below-ground, began to equal or exceed those of natural beds after 3 yr, but declined relative to natural beds after 6.5 yr. It is unknown whether this is an artifact or represents other factors such as nutrient limitation or genetic effects. Root : shoot ratios initially were higher in restored beds but were similar to those of natural beds after 3 yr. Sediment organics in restored beds were typically lower than those observed in natural beds. Seasonal variations and patchiness in deposition of detritus likely overrode any cumulative signature. Sand : silt : clay ratios indicated higher sand contents in restored beds but hinted at the slow increase in fine silts and clays over time. The build-up of fines is important for nutrient regeneration within the restored bed and for fueling the detritus-based food web from bacteria up to fishes. Fish and decapod densities remained low in restored beds for the first 3 yr relative to natural beds, then equaled or exceeded those in natural beds in following years. The lag period was similar to that observed for seagrass coverage. The superabundance of organisms may have been related to construction aspects that created protected shorelines or limited the access of predators. Dominant macrofaunal species were similar between restored and natural seagrasses during most sampling periods. Benthic communities are still under investigation, but preliminary data indicate similar numbers in each habitat after 3 to 4 yr. We do not know how long it will take benthic communities in restored beds to resemble those found in natural beds, but it has been suggested in previous studies that > 15 yr may be needed. This may be related to accumulation of fine materials in the sediments. Restored *Halodule* beds in Texas appear to need at least 3 to 4 yr to structurally resemble adjacent natural seagrasses. Some components have not reached equivalence even after 8 yr. Unfortunately, the state of knowledge concerning functional equivalence (energy flow, biogeochemical cycling, trophic relationships, etc.) remains poor here and elsewhere.

Smith, Daniel L., and C. Edward Proffitt. Louisiana Environmental Research Center, McNeese State University, Lake Charles, LA. **AMONG CLONE DIFFERENCES IN *SPARTINA ALTERNIFLORA* L. IN RESPONSE TO EXPERIMENTAL TREATMENTS OF CRUDE OIL AND REMEDIATION BURNING.** The potential for variation among different genets in plant responses to oil spills and remediation burning of oil has received little attention. We performed a greenhouse experiment using ramets from three genets collected from spatially-distinct clonal patches of the salt marsh grass *Spartina alterniflora* Loisel in a restoration site at the Sabine National Wildlife refuge. At the refuge, patches were located approximately the same distance from open water and were growing at similar elevations on sediments that were relatively homogeneous due to mixing during the dredging process. These factors greatly reduced the potential for between-clone differences in environmental growing conditions. Experiment main effects were oil-only (levels 0, 4, 8, 16 and 24 L/square meter) and oiled-and-burned (levels: unburned or burned) applied to the 3 clones (3 ramets/pot and 10 replicate pots in each treatment) in a fully-crossed design. Unweathered Venezuelan crude oil was applied to the water saturated sediment surface of potted plants. In burn treatments, crude oil was ignited with a butane torch. Plants in which all above-ground biomass was burned away with a butane torch served as a burn control. Burning proved effective in removing up to 40% of the oil from the sediment and the percent of oil removed by burning did not vary with the oil concentration applied. For biological variables such as culm density, shoot height and plant biomass there was a significant effect of oiling and burning, and evidence for "successful" remediation of oil effects by burning at an intermediate oil concentration, and in the oiled-and-burned plants there was among clone-differences in survival, culm density, shoot height and plant biomass. In general, the percent survival of plants that were oiled and burned decreased with increasing oil concentrations and was much lower than that of the oil-only treatments. There was no effect on culm density and shoot height at oil applications up to 8 L/square meter. Vegetation that was oiled and burned grew back rapidly at oil concentrations up to 16 L/square meter, but at the higher oil applications, burning lasted longer and the negative effects of oil were exacerbated. Flowering occurred more frequently in the oil-only than the oil and burn treatments, but in both cases flowering decreased with increasing oil concentrations. The data suggest that genetic variation may be affected by oil spills and/or remediation burning. Burning appears to be an effective remediation tool at oil concentrations of 16 L/square meter.

Sutula, M. [1], B. Perez [1], E. Reyes [1], J. W. Day [1], D. Childers [2], and N. Oehm [2]. [1] Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA and [2] Southeast Environmental Research Program, Florida International University, Miami, FL. **ANNUAL NUTRIENT EXCHANGE BETWEEN NE FLORIDA BAY AND A MANGROVE CREEK IN THE SOUTHERN EVERGLADES.** Hydrological restoration of the Everglades will result in increased freshwater flow to Florida Bay. The exchange of nutrients between Taylor River and NE Florida Bay was measured to establish baseline estimates of nutrient flux before restoration work begins. Specifically,

the objectives were to quantify the annual flux of nutrients from Taylor River and determine the importance of relative effect of freshwater flow, rainfall, wind-driven and tidal forcing on water exchange and nutrient concentration at the mouth of the creek. Five 10-day intensive studies were conducted during the months of May, August, November 1996, January and May 1997 to determine the flux of dissolved inorganic and total N and P. A daily record of TN and TP flux was generated from daily water samples taken from May 1, 1996 through April 31, 1997, and flow was recorded at the creek mouth in 15-minute intervals through out this period. There was an annual export of TP and TN of magnitude of 7998 moles yr^{-1} and 1,521,163 moles yr^{-1} respectively. Water exchange was influenced to a greater extent by freshwater flow and wind than by tide or local rainfall. Organic N and P dominated total nutrient flux during the five sampling periods (89 - 94%). Peak TP and TN export occurred during the beginning of the rainy season coincident with heavy rainfall in the watershed, while peak import was associated with wind-driven forcing. TN concentration was highly correlated with freshwater flow, while rainfall may be an important source of TP.

Turner, Jason P. and Graham A. J. Worthy. Physiological Ecology and Bioenergetics Lab, Texas A&M University at Galveston, Galveston, TX. **DIFFERENTIATING POPULATIONS OF BOTTLENOSE DOLPHINS (*TURSIOPS TRUNCATUS*) IN THE GULF OF MEXICO USING SKULL MORPHOMETRICS.** The current taxonomic status of the bottlenose dolphin in the Gulf of Mexico is that of a single species, *Tursiops truncatus*, although significant variability has been described on global and local scales. One hypothesis explaining this phenomenon is that the species is locally divided into both coastal populations comprised of small, elongate animals, and offshore populations made up of large, robust animals. A single morphometric study of bottlenose dolphin skulls in the Atlantic found that separation did occur between inshore and offshore animals, however, no such studies have been conducted in the Gulf of Mexico. To test this hypothesis in the Gulf of Mexico, 220 skulls were collected from stranded animals encompassing Mississippi (n=1), Louisiana (n=9), Florida (n=59), and six stranding areas from Texas (n=151). Data on standard length, sex, location of stranding, and a sample of teeth for aging were collected. While the specimens were obtained from stranding situations, and therefore of unknown origin, 37 animals were taken from known inshore communities. The inshore sample was comprised of specimens collected from coastal gillnets (n=3), strandings of photo-identified animals (n=16), and from die-off events within local bay communities (n=18). Thirty-five cranial measurements, from Perrin (1975) and Walker (1981), were examined along with age, sex, standard length, skull maturity, and geographic location of stranding. Characters were grouped based upon functionality and used to compare groups from Texas and Florida, belonging to known inshore populations and stranded animals from unknown populations. Cluster analysis identified a small group of animals (n=5) that were significantly different from the rest of the dolphins. Due to the shape and size of the characters exhibited by the skulls of these animals, they were hypothesized to be "offshore" animals. Discriminate analysis determined that traits defining skull length, feeding musculature, and nares shape identified separation between Texas inshore and Texas "offshore" populations, while traits defining width of rostrum and internal nares identified separation between Texas and Florida populations. Further investigation found that separation between the inshore and offshore dolphin populations could be determined by as few as three skull characters, consistent with findings from populations in the Atlantic Ocean. Future research will attempt to correlate these traits with feeding ecology and to develop a standard suite of measurements ranges which could be used to identify animals within managed areas.

Turner, R. Eugene. Coastal Ecology Institute, Louisiana State University, Baton Rouge, LA. **ESTUARINE SIGNATURES FOR THE GULF OF MEXICO.** The large variability among US estuaries both reflects and disguises underlying relationships between the physics and biology of estuaries. Important parameters of estuarine variability include morphology, flushing times, nutrient loading rates and wetland:water ratios, to name a few. The Gulf of Mexico (GOM) estuaries have 28% and 41% of the US estuarine wetlands and open water, respectively, and vary by 100 Xs within the GOM. The average freshwater turnover time appears to be faster (shorter residence time) in the Gulf of Mexico estuaries, compared to all others (average 184 days). Within the GOM, estuarine nitrogen, phosphorus and suspended matter loading varies over 2 orders of magnitude. This regional variability demonstrates a pattern of higher wetland:open water ratios with increasing suspended loading rates, but a distinct cluster of northeast estuaries that is separate from all others. Anoxic estuarine events tend to be those with slow freshwater turnover and high nitrogen loading.

VanderKooy, Kathy E., Chet F. Rakocinski, and Richard W. Heard. The University of Southern Mississippi, Institute of Marine Sciences, Gulf Coast Research Laboratory, Ocean Springs, MS. **TROPHIC RELATIONSHIPS OF THREE *LEPOMIS* SPP. LIVING IN AN ESTUARINE BAYOU.** By studying feeding patterns and habitat use among three co-occurring sunfishes, we can gain a better understanding of their associations in estuarine submerged vegetation. *Lepomis miniatus* (redspotted sunfish), *L. microlophus* (redear sunfish), and *L. macrochirus* (bluegill) were collected from an oligo-mesohaline bayou in Ocean Springs, Mississippi. Fish and prey availability samples were taken from March 1994 - January 1995. A total of 609 stomachs were examined from fishes representing three size classes. Based on diet composition, some degree of spatial segregation in feeding habitat occurred among the species. However, a high degree of trophic overlap existed among small size classes of all three species. Submerged aquatic vegetation (SAV) was an important feeding habitat for all sunfishes, and also provided an important refuge area for juvenile sunfishes. But trophic overlap among species was reduced by the use of forage areas other than SAV. Diet composition and use of feeding habitats changed seasonally. During spring and summer, fishes utilized SAV and sediment for feeding habitats. However, during autumn, all fishes increased their use of SAV for feeding. This increased use of SAV habitat for feeding coincided with declining SAV coverage, suggesting that competition during autumn was greater than in other seasons.

Withers, Kim and Jace W. Tunnell. Center for Coastal Studies, Texas A&M University - Corpus Christi, Corpus Christi, TX. **FAUNAL SUCCESSION IN BRACKISH, EPHEMERAL PONDS IN A HIGH MARSH ON THE CENTRAL TEXAS COAST.** Three brackish, ephemeral ponds located in a high marsh near Chiltipin Creek in San Patricio County, Texas were studied between October 1992 and October 1995 to determine if faunal abundances were affected by in situ burning used to clean up an oil spill caused by a ruptured pipeline. Two "treatment" and one "control" ponds were studied. Thirty-six invertebrate and four fish species were collected throughout the study. Of the invertebrates, four phyla were represented (Nematoda, Annelida, Arthropoda, Mollusca). Arthropods, primarily insects in the orders Hemiptera and Coleoptera, dominated collections during all three years. There was little pattern to the occurrence or abundance of taxa found in ponds except as a function of the filling and drying of ponds. However, the striking resemblance of Year 1 and Year 3 faunas (in terms of overall relative abundances) suggests that there may be multi-year cycles of succession and population abundance superimposed on the short-term succession required by the ephemeral nature of these ponds. There was no evidence that the oil spill and/or subsequent burn impacted the fauna inhabiting the ponds.

Williams, Patrick R.[1] and Richard E. Condrey[2]. [1] Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA and [2] Coastal Fisheries Institute, Louisiana State University, Baton Rouge, LA. **PRELIMINARY ASSESSMENT OF NEKTON ASSEMBLAGES ASSOCIATED WITH THE BARRIER ISLAND AQUATIC HABITATS OF EAST TIMBALIER ISLAND, LOUISIANA.** The rapid deterioration of barrier islands is cause for national concern because these islands provide substantial biogeomorphic and socio-economic functions. Evaluation of fisheries habitat provided by barrier islands is essential in resource management to help resolve utilization and preservation conflicts and to examine the success of habitat protection and restoration efforts. A total of 71,841 specimens representing 87 nekton species were collected from tidal creek, surf zone, lagoon, tidal channel, sandflat, and vegetated edge habitats on East Timbalier Island, Louisiana by bag seine, otter trawl, and hand trawl during February to August, 1997. Principal components analysis identified seven assemblages accounting for approximately 30% of the total variance. Of these principal components, all had significant differences between months and four exhibited differences between habitats. Species diversity, richness, and eveness were also evaluated. These data will be used to identify which habitats are most important to fisheries resources, for use in future habitat restoration and creation projects.

Young, Jennifer S. and C. Edward Proffitt. Louisiana Environmental Research Center, McNeese State University, Lake Charles, LA. **COMPARISONS OF PLANT COMMUNITY DEVELOPMENT IN RESTORED AND NATURAL COASTAL MARSHES.** Growth and structure of marsh plant communities colonizing large flats of dredged sediments is being studied at the Sabine National Wildlife Refuge in southwestern Louisiana. Three created sites (ages 1.5, 5 and 15 years) are being studied as are two natural reference marshes. All sites were dominated by smooth cordgrass, *Spartina alterniflora*. The 15 year old site was populated by an apparent short form and the other sites were characterized by tall form *S. alterniflora*. We measured growth, density, biomass and environmental conditions at marsh edge and interior locations. The 1.5 and 5 year old sites have numerous circular clones some of which were marked for clonal growth studies. Clones were separated by bare ground or lawns of *Salicornia bigelovii*. Patches of *S. patens* and *Distichlis spicata*

also occurred in higher elevations but at very low percent cover. Salinities of ground and surface water are similar to that measured in the nearby Hog Island Gully canal (range: 0 - 32 mg/L). Temperatures in summer were significantly lower under *S. alterniflora* canopy ($P<0.05$). Within a marsh, there were no significant differences in height of *S. alterniflora* at marsh edge and interior locations, however, heights were significantly less in the 15 year old marsh ($P<0.0005$). Ramet densities and above ground biomass were greatest in the oldest restored marsh, and edge and interior locations did not show differences in ramet densities. The oldest created marsh has cover and biomass of *S. alterniflora* comparable to the natural reference marshes. In higher elevations in the 5 year old marsh, *S. alterniflora* clones (some >7 m in radius) were serving as nodes for colonization by several other species including *Baccharis halimifolia* and *Iva frutescens*. Neither of these species colonized bare ground, but only clones of *S. alterniflora*.

Zobrist, Erik C. National Marine Fisheries Service, Habitat Restoration Division, Silver Spring, MD. **CORAL REEF RESTORATION AND PROTECTION FROM VESSEL GROUNDINGS.** Major vessel groundings in the Florida Keys National Marine Sanctuary such as the M/V *Alec Owen Maitland* (Carysfort Reef), the M/V *Elpis* (The Elbow reef) in 1989 and the R/V *Iselin* in 1994 (Looe Key) have demonstrated the need for quick response when restoring injured coral reef habitat. The *Maitland* and *Elpis* sites were not restored until 1995. During the intervening period, waves and currents enlarged the injury and required major physical reconstruction of the reefs. While highly successful, the value of quick response was learned. While under litigation with the *Iselin* Potential Responsible Party (PRP), NOAA directed an operation which removed several hundred tons of loose coral rubble which threatened adjacent undisturbed coral habitat within a year of the grounding. Recently, NOAA had the opportunity to take actions to restore injured coral reef habitat quickly. The 600-foot Contship *Houston* ran aground near Key West in February, 1997. Coral heads were toppled and scattered on the sea floor generating a large volume of loose rubble. NOAA and the State of Florida were able to work with a cooperative PRP and completed an emergency restoration phase in Spring, 1997 which reattached live coral heads and fragments. Five rubble berms were stabilize with a non-toxic marine epoxy. Two large rubble berms were stabilized with flexible concrete mats and 2-3' diameter boulders while two other sites were stabilized with just boulders. In July, 1997, the 325-foot M/V *Fortuna Reefer* container ship ran hard aground near Mona Island, Puerto Rico. The vessel injured about 6,400 square meters of coral reef dominated by elkhorn coral, *Acropora palmata*. As a result of an expedited settlement between the trustees and the PRP, NOAA initiated emergency restoration of 1,857 broken elkhorn coral branches in September and complete the effort in mid-October. The objectives of the emergency restoration were to reverse the major impacts of the grounding by reestablishing the physical structure of the coral reef community and reduce coral mortality by removing the largest broken pieces of branching elkhorn coral from the seafloor and re-attaching them before they succumb to winter-storm damage. Through NOAA's Damage Assessment and Restoration Program, a solid scientific and strong legal case can facilitate either a cooperative relationship between the trustees and the PRP or encourage a timely settlement. These two cases demonstrate two means by which State and Federal trustees can restore coral reef habitat quickly, cost-effectively and without prolonged legal proceedings.